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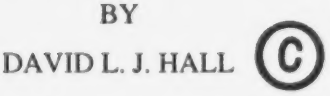
DAVID L. J. HALL 

A THESIS SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

DEPARTMENT OF PSYCHOLOGY

EDMONTON, ALBERTA

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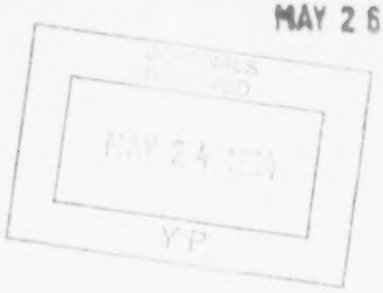

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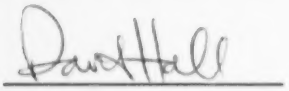

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This work is dedicated to my best friend, Susan, whose unwavering support made it possible.

Abstract

When people are shown large (global) letters made from small (local) letters, the time to name local letters increases when the identities of the global and local letters are different relative to when identities are the same. However, local letter identity seldom interferes with time to name global letters. These findings are congruent with global-to-local theories of visual recognition in which global information is available first and dominates early visual processing (global precedence). One implication of this framework is that global identity and global orientation are available before local identity and local orientation. Most studies have used letters as stimuli; experiments with non-alphabetic stimuli have sometimes produced contradictory results. Moreover, the relative availability of global vs. local identity and orientation is an open empirical issue. Four experiments showed that global precedence for letter identification generalized to identification and orientation decisions of geometric shapes. Local decisions were slower for letters than shapes, and on identity decisions there was more global interference for letters than shapes. Contrary to strict global-to-local theory, global and local identity was available before global and local orientation for both kinds of stimuli. Moreover, local interference was also present on decisions of global identity and orientation. It is suggested that at least some global and local information is available simultaneously, and that global precedence is partly due to influence at a decision level when information from multiple sources is sorted out. A model is discussed to account for the data. The point is made that global and local features have qualitative differences that probably contribute to differences between global and local processing.

Acknowledgement

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Global Precedence for Identity and Orientation Decisions about Letters and Geometric Shapes

One account of how we obtain visual information during object recognition assumes that the early output of visual processing is a coarse representation of shape and orientation, and that fine details of shape and orientation of features become available after subsequent processing (Navon, 1977, 1981). Thus, the overall (global) shape of a pattern is available before the shape of its elementary units (i.e., local features). A "global-to-local" sequence is consistent with many theories for visual processing and models of visual object recognition (e.g., Bouma, 1971; Grimson, 1980, 1984; Humphreys, 1983, 1984; Marr & Nishihara, 1978; Marr & Poggio, 1979; Palmer, 1989; Pentland, 1989; Townsend, Hu, & Kadlec, 1988; Watt, 1988; Watt & Morgan, 1985). Two implications of this framework are that identification of local features is influenced by global information (i.e., global precedence; Navon, 1977, 1981), and that global identity and orientation are available before local identity and orientation.

In contrast to the view that visual processing follows a global-to-local sequence, at least two major theories of visual object recognition assume that the sequence is local-to-global (Selfridge, 1959; Treisman, 1988, see also Biederman, 1987). On this view, information about locally-defined features is processed automatically and rapidly by the visual system, and local features are identified without influence from global information.

The current experiments use compound stimuli in which large (global) letters are made up of small (local) letters (see Figure 1), and in which global shapes are made up

of smaller, local shapes. Navon (1977; see also Kinchla, 1974) suggested that such stimuli controlled properties of global and local features with respect to complexity, salience, recognizability, and relative diagnosticity. One purpose of these experiments was to investigate whether global precedence is a general principle for visual recognition that is independent of type of stimulus.

Arguments supporting global precedence are often based on data derived from letters as stimuli; however, letter recognition might involve processes associated with reading that do not generalize to recognition of non-letter shapes (e.g., Friedman, 1980). Indeed, there is strong evidence against assuming that results from letter identification tasks necessarily apply to visual processing of non-letter shapes (Dawson & Harshman, 1986; Dixon & Twilley, 1988). Moreover, Dawson and Harshman (1986) argued that whether the sequence of processing was global-to-local or local-to-global depended on whether the stimuli were letters or non-letters. Although others have used non-letter stimuli to investigate global processing (for example; Boer & Keuss, 1982; Hughes, Layton, Baird, & Lester, 1984; Kitterle, Christman, & Conesa, 1993; Navon, 1977; Palmer, 1980; Palmer & Bucher, 1981) these researchers have not compared them directly with letter stimuli using the global-local paradigm. The current experiments directly compare letter and non-letter stimuli that have the same physical dimensions (e.g., size, luminance, and overall complexity).

A second purpose of these experiments is to provide further evidence for that global precedence extends to information other than identity; in particular, orientation information. This point is important, because the role of orientation information is

central to major theories of object recognition (Biederman, 1987; Marr, 1982; Rock, 1973). For example, whereas some theorists argue that global orientation is used for recognition (Marr & Nishihara, 1978; Rock, 1973), others disagree (e.g., Biederman, 1987). Therefore, strong evidence for or against global precedence of orientation information can support one or the other arguments, and these experiments were designed to produce such evidence.

Thirdly, the current experiments were also designed to test the sequence of availability of identity and orientation information for both letter and non-letter stimuli. According to some theories (Biederman, 1987; Treisman, 1988) identity of local features is available before global orientation, while others (e.g., Marr, 1982) assume that global orientation is recognized before local identity. According to strong global-to-local theory, global identity and global orientation should be available before local identity and local orientation for letters and non-letters alike. Despite its importance to theories of visual recognition, data regarding this issue were sparse prior to the current investigation.

In this paper, I first introduce ideas underlying theories of local-to-global processing of visual information, and then outline data supporting these ideas (Treisman & Gormican, 1988; Biederman & Cooper, 1991a, 1991b). Second, I contrast local-to-global with global-to-local processing, and review data that supports the idea of global precedence in visual processing (Earhard, 1990; Hughes, et al., 1984; Navon, 1977; Palmer, 1980; Paquet, 1992; Paquet & Merikle, 1984; Sanocki, 1991, 1993). Third, I

describe four experiments that were designed to investigate global precedence in visual recognition.

Local-to-Global Processing

The defining characteristics of local-to-global theories (e.g., Biederman, 1987; Treisman, 1988) are that visual processing begins at the local level, that the representation of global shape and global orientation is attained (if at all) only after primitive units or features are combined in some way, and that processing of detail at the local level is not influenced by results of processing at the global level. Support for the notion that the visual system detects features early in processing comes from single cell recordings (e.g., Hubel & Wiesel, 1979) demonstrating the existence of neurons that are "tuned" to respond to line segments at particular orientations, and visual search experiments in which locally-defined features are detected rapidly and apparently effortlessly (Treisman, 1988; Treisman & Gormican, 1988; Enns, 1992; Enns & Rensink, 1990, 1991).

Important issues for local-to-global theories include what defines a primitive unit (or feature) and how these features are bound together to obtain a complete representation. These issues have been reviewed elsewhere (Pinker, 1984; Hummel & Biederman, 1992; Livingstone & Hubel, 1988; Treisman, 1988), and detailed discussion of them is beyond the scope of the current paper. The focus of the current paper is the assumption shared by such theories that visual processing begins at a local (element) level, and that processing at the local level is independent of results of processing at the global level.

According to Treisman's (1988) feature integration theory, the first stage of visual recognition is the automatic and parallel detection of features, which are combined in a later stage (feature binding). Examples of features are color, curvature, and orientation (Treisman & Gelade, 1980; Treisman & Gormican, 1988). According to feature integration theory, the representation of a shape made of conjoined features is available only after local features have been integrated. By this notion, it should be more difficult to discriminate letters that share features than to discriminate letters made of distinct features. For example, whereas P's can be discriminated from T's by the presence of a single feature (curvature), R's are discriminated from a field of P's and Q's by a conjunction of features (curvature and tilt). Consistent with a feature integration model, Treisman and Gelade (1980) found that R's were difficult to detect in a field of P's and Q's.

A second example of local-to-global theory is Biederman's (1987) Recognition by Components theory of object recognition. According to Biederman, (1987; Hummel & Biederman, 1992) the recognition process uses local cues such as concavities and co-terminations to parse an object's components (geons), and an object's shape is represented in terms of a conglomerate of geons and the spatial relations between them. Biederman (1988, page 385) argues that the global contour (such as that afforded by a silhouette) is a less effective cue to object identification than are internal contours. Moreover, although there is a strong effect from local (component geon) shape on reaction time and accuracy for recognition, Biederman and Cooper (1991a, 1991b) found little to no effect from global shape. Thus, global contour is accorded no special status

in Biederman's theory, and neither global contour nor global orientation are included in a recent instantiation of the theory (Hummel & Biederman, 1992).

From the present perspective, both Biederman (1987; Cooper, Biederman, & Hummel, 1992) and Treisman (1988) propose that object recognition proceeds by extraction of image features. Local information (i.e., features or geons) is encoded rapidly, but local primitives (i.e., features or geons) must be bound to form a representation of an object's global shape. Thus, initial processing of global information does not precede processing of local information.

With respect to local-to-global theories in general, three points are important for this paper. First, according to strong local-to-global theory, local features become available to the visual system before global shape does. Second, the orientation of local features (or units) is available before the orientation of the global configuration. Third, local-to-global models (including Treisman, 1988; Biederman, 1987; Hummel & Biederman, 1992) employ passive bottom-up processing such that processing of local features (or geons) is an independent stage uninfluenced by global shape or orientation. Therefore, decisions about local identity and local orientation should be uninfluenced by global identity and global orientation. In addition, assuming that decision time reflects availability, decisions about local identity and local orientation should be faster than decisions about global information.

Global-to-Local Processing

In contrast to theories of local to-global processing, theories of global-to-local processing assume that the output of early visual processing is relatively low-resolution

global information (e.g. Lupker, 1979; Navon, 1977; 1981). Therefore, a representation of overall shape and orientation is attained before a representation of local features, the representation of global shape is not wholly determined by the shape of local (component) features, and the results of processing at a global level guide the processing of local detail. Navon (1977) used an example in which objects in a scene were represented as blobs. As processing progressed, the blobs were differentiated and refined.

Consistent with Navon's (1977) framework, Lupker (1979) articulated the sequence of visual processing using a coarse-to-fine focusing analogy (see also Bouma, 1971; Navon, 1977, Townsend, Hu, & Kadlec, 1988), in which the output of coarse processing is similar to an object being presented out of focus; thus, more global than local aspects are available, such as general shape, height to width ratio, and main axis of elongation. The output of fine processing would be as though the object is presented in focus; thus, relatively more local information is available such as local features, component axes, and how inner parts are arranged. Lupker (1979; also see Boer & Keuss, 1982; Navon, 1977; 1981) suggested that only at a fine level does the observer have the information traditionally thought of as features. There are a number of formal definitions of coarse-to-fine visual processing that are consistent with Lupker's analogy (e.g., spatial frequency; Gervais, Harvey, & Roberts, 1984; Hughes, Fendrich, & Reuter-Lorenz, 1990; Hughes, et al., 1984; Marr & Hildreth, 1980; Watt, 1988; Wilson & Bergen 1979, pattern envelopes; Bouma, 1971, and generalized cylinders; Marr, 1977; Marr & Nishihara, 1978).

In accordance with the focusing analogy, Bouma (1971) found that lower-case letters which shared similar outlines (for example, y and p) were more likely to be confused than those which shared similar features but had dissimilar outlines (c and d), and Lupker (1979) found that the probability of confusing X with V decreased as display time increased. Lupker (1979) also found that the top-heavy T and the bottom-heavy L were seldom confused, because these could be discriminated at a coarse level early in processing. As pointed out earlier, a typical local-to-global feature model would predict that letters would be confused as a function of the number of shared features, rather than as a function of the similarity of global outlines.

A coarse-to-fine sequence is consistent with a number of theories of object recognition in which a coarse, blob-like representation of an object is obtained early in the recognition process, and finer details are subsequently recognized (Bouma, 1971; Marr & Nishihara, 1978; Pentland, 1986; Townsend, Hu, & Kadlec, 1988; Watt, 1988). For example, several theorists (Humphreys, 1983, 1984; Marr, 1982; Marr & Nishihara, 1978), argue that an object's main axis has primary importance for recognition, and local features of a shape are coded relative to the main axis. A coarse representation can enable an object's main axis of elongation to be recognized first (see Humphreys, 1983; Marr & Nishihara, 1978; Palmer, 1989). Minor axes of component parts and the spatial relations between the minor axes are identified at a finer level of coding. The orientation of an object's main axis is also the global orientation for that object; thus, according to this axis-based theory, global orientation would be recognized before local features would be identified (see also, Humphreys 1983, 1984; Humphreys & Quinlan, 1988).

Navon (1977, 1981) and Paquet (1992) argue that the analysis of the global aspect of a form dominates early processing, and that an indicator of this dominance is that the global identity interferes with response time and accuracy of identifying local features. To compare effects of both global and local information it is important to use stimuli that contain both global and local information, and tasks that require decisions about both levels.

Global Precedence in Visual Processing

In Navon's (1977) classic investigation of global and local processing, subjects were shown compound stimuli made of Hs and Ss. The global and local letters were crossed factorially; thus, stimuli were either globally and locally consistent (e.g., a large H made up of small Hs) or were conflicting (e.g. a large H made up of small Ss). Subjects were asked to identify either the global letters or the local letters. Navon (1977) found that identification of global letters was faster than identification of local letters. Moreover, there was asymmetrical interference because reaction times were slowed when global-local aspects conflicted, but only for identification of local letters. Navon (1977) argued that the faster reaction times for identification of global letters and the finding of asymmetrical interference support the idea that global information has priority over local information in visual processing; he termed this effect global precedence.

Although many global-local investigations have been limited to identity judgments, Navon's (1977) claim regarding global precedence was intended for visual processing in general, which applies to orientation as well as identity information. According to local-to-global theories (e.g., Biederman, 1987), local orientation (e.g., orientation of

geons) is important for recognition but global orientation (i.e., orientation of the shape as a whole) is not. Biederman (1987, Cooper, Biederman & Hummel, 1992) argues that the mental representation used for object recognition is independent of properties associated with viewpoint, including size, position, and orientation. This idea is supported by evidence that recognizing object identity and spatial position involve dissociable cortical pathways (Ungerleider & Mishkin, 1982). Although it is arguable whether identity and orientation are independent, according to a strong local-to-global theory, global orientation does not influence local identity, and importantly, local identity is processed before global orientation.

In contrast to local-to-global theories, global-to-local theories (Marr & Nishihara, 1978; Rock, 1973) stress the importance of global orientation for recognition. For example, if an object's local features are encoded with respect to the main axis, (Humphreys 1983, 1984; Humphreys & Quinlan, 1988; Marr & Nishihara, 1978) then identification of an object's local features should be dependent on the processing of global shape and global orientation. The current investigation treats shape identity and orientation as separable dimensions, but whether or not these dimensions are represented independently is arguable (for discussion, see Biederman & Cooper, 1992; Pinker, 1984; Verfaillie, 1992). For the current purpose, it is assumed that identity and orientation are functionally independent.

Whether or not an object's global orientation is available before the identity of its local features was an open empirical question prior to the current experiments. Moreover, although most researchers have reported effects of global precedence on

orientation judgments (Boer & Keuss, 1982; Hughes, et al., 1984; Kitterle, et al., 1993; Navon, 1977; Palmer, 1980; Palmer & Bucher, 1981), there are some gaps in the evidence. for example, some investigators have found global precedence using very simple stimuli such as line gratings (Kitterle et al., 1993) and line segments (Hughes et al. 1984). Those who have used complete shapes have used ambiguous figures such as equilateral triangles (Palmer, 1980; Palmer & Bucher, 1981). The current experiments provide evidence for precedence of global orientation using shapes that have local features with non-ambiguous orientations.

Navon (1977, Experiment 4) provided the first evidence for global precedence of orientation information in his original study. He used stimuli that were triads of squares, arranged to make global and local isosceles triangles (see Figure 3). Pairs of stimuli were either identical, or had different global or local orientations. He found that global orientation differences were correctly detected more frequently than local differences, and concluded that, for brief exposures, a global configuration was more likely to be perceived than a local configuration. This study is important because it is among the first to use the global-local paradigm with stimuli that are not letters. However, there was no direct comparison between letter and non-letter stimuli and Navon (1977) did not investigate the time course of identity and orientation information.

Hughes, Layton, Baird, and Lester (1984) also found evidence for global precedence of orientation information. Stimuli were rectangular clusters of homogenously oriented line segments. Local (line segment) orientation was vertical or horizontal, and was varied orthogonally with global (cluster) orientation. Control conditions were rectangular

patterns of dots (global orientation but no local orientation) and un-clustered line segments (local orientation but no global orientation). Hughes et al. (1984) found that time for judgments of global and local orientation were equivalent when global and local cues were presented in isolation. However, when local and global cues were presented together, judgments of local orientation were slowed relative to the control condition, but global judgments were unaffected by local cues.

Hughes et al. (1984) applied Sternberg's (1969) additive-factors method to determine whether the origin of global precedence was a stage of early visual processing, or whether it originated from later processing such as response competition. They used density filters to vary the luminance of the display, under the assumption that luminance would influence early processes of stimulus encoding. According to additive-factors logic, factors that have interactive effects on reaction times influence the same processing stage, whereas additive effects indicate that the factors influence different processing stages. The results were again consistent with global precedence because local orientation judgments were slower when global and local orientations conflicted relative to the control (single cue) condition, but global judgments were not influenced by local orientation. Moreover, there was a reliable interaction, such that global precedence grew as luminance was reduced. Hughes et al. (1984) argued that the interaction of global precedence with luminance indicated that global judgments were at least partly attributable to early visual processes. Boer and Keuss (1982) had previously argued that global precedence effects on orientation judgments are due to

post-perceptual effects, but they did not measure both global and local orientation decisions.

Although the Hughes et al. (1984) findings are promising regarding early visual processing of global orientation information, the stimuli were simple line features. It is possible that decisions based on visual information about single features might produce different results than decisions about more complex shapes. For example, although there is a left hemisphere advantage in identifying the orientation of high spatial frequency gratings (Kitterle et. al., 1993), Biederman and Cooper (1991c) report that no laterality effects are evident when objects are identified.

Palmer (1980; Palmer & Bucher, 1981; for discussion, see Palmer 1989) showed displays of groups of equilateral triangles, and asked people to decide which way a central triangle pointed. The probability (Palmer, 1980) and reaction time (Palmer & Bucher, 1981) for any given orientation decision was influenced by the overall arrangement of the group of triangles with respect to a globally-defined axis. Thus, global orientation influenced judgments of local orientation. Palmer (1980) also used displays in which a single central equilateral triangle was flanked by squares. The probability of seeing the triangle point in a given direction was again influenced by the orientation of a globally-defined axis, but also by the orientation of the flanking squares. Palmer (1980) concluded that global levels affected local levels for orientation decisions, but that there were also processes that interacted among units within a given level. He suggested that some processing might be more global than a single element, but not as global as the entire configuration. Palmer (1980, 1989; Palmer & Bucher, 1981; also

Lamb & Robertson, 1988) suggested that more than one process is needed to account for influence from both global and local levels. He argued that neither a strict global-to-local theory nor a strict local-to-global theory would hold for orientation decisions, but that whether local levels could affect more global ones was an open question.

It is important to note that equilateral triangles are ambiguous with respect to orientation. Humphreys (1983, 1984; Humphreys & Quinlan, 1988) argues that objects with an ambiguous main axis are difficult to recognize, because object recognition includes identifying a main axis. Thus, it is possible that Palmer's (1980; also Luna, Merino, & Marcos-Ruiz, 1990) findings might not generalize to local and global decisions using shapes that have an inherent orientation. That is, the orientation of a globally defined axis might have less influence on decisions regarding local shapes when the main axis of the local shapes is easy to identify.

Global precedence for orientation might be associated only with aligning ambiguous shapes and line segments, and not be an important factor for visual recognition in general. Therefore, it is important to demonstrate global precedence for orientation decisions across stimuli that have unambiguous global and local orientations. Moreover, Palmer's (1980; Palmer & Bucher, 1981) experiments were not designed to study shape decisions; therefore, the issue regarding relative availability of global orientation and local identity was not addressed.

Global precedence, and in particular, asymmetrical interference, might be due to either or both of two possibilities. One possibility is that global information dominates processing during a stage later than encoding. This might be due to attentional factors,

strategy, or other top-down influences. Another possibility is temporal precedence, such that processing of global features is initiated first and for this reason global features predominate in early processing. These possibilities, and issues arising from them, will be discussed next.

Processing Dominance and Temporal Precedence

A simple explanation for global precedence is that global features are more easily processed because they are large (Schultz & Eriksen, 1978), or within an optimal range of visual angle (Kinchla and Wolfe, 1979). However, individually presented small letters that are the same size as local letters in compound stimuli are processed as rapidly as global letters (Navon, 1977, 1981; Navon & Norman, 1983). Also, Navon and Norman (1983) used a circular display in which local features were presented at the same eccentricity as global features. Results showed that visual angle alone could not account for global precedence when eccentricity was controlled (see also, Luna, et al., 1990). Thus, although size might be a relevant factor, relative size is more important than absolute size in producing effects of global precedence (Navon, 1977, 1981; Navon & Norman, 1983).

There is evidence that the priority of global information for recognition is subject to attentional factors (Earhard, 1990; Earhard & Walker, 1985; Lamb & Robertson, 1988; Miller, 1981; Ward, 1982), but non-attended global information can influence decisions about local information (Paquet, 1992; Paquet & Merikle, 1988). Paquet (1992; Paquet & Merikle, 1988) tested whether global processing was mandatory for both attended and non-attended information. Stimuli were compounds made of H , E, and O, and were

presented in pairs. Targets were H and E, with the letter Q used as a neutral stimulus. People were cued to identify either the global or the local letter in one member of each pair and to ignore the other compound letter entirely. The global and local letters in the non-attended stimulus were either consistent, conflicting, or neutral with respect to the target letters in the attended stimulus. The global and local letters in the attended stimulus were also either consistent, conflicting, or neutral. For attended stimuli, global letters were responded to more quickly than local letters, conflicting conditions slowed reaction times, and interference from global letters was harder to ignore than interference from local letters. Importantly, both global and local identification was slowed when the global feature of the non-attended stimulus was a member of the target set compared to the neutral condition. However, time for global identification was not influenced by local features of the non-attended stimuli. Paquet (1992; Paquet & Merikle, 1988) concluded that global information dominated during both attentive and pre-attentive processing, and that some amount of global processing was mandatory even for non-attended information.

The conclusion that some global processing is mandatory but local processing can be selectively attended is consistent with global-to-local theory. However, Paquet (1992; Paquet & Merikle, 1988) only used a letter identification task; therefore, no conclusions can be drawn regarding global or local orientation processing, or for the generality of these findings to other types of stimuli. Moreover, somewhat conflicting results were reported by Boucart and Humphreys (1992).

Boucart and Humphreys (1992, p. 791) suggested that objects are identified using local structural information, and that the parts of an object can interfere with extraction of global shape information. They argued that line drawings of natural objects were identified automatically, and that access to global shape does not occur without object identification. They asked people to judge which of two comparison forms had the same global shape (i.e., round or oval) as a reference stimulus; thus, the identity of the stimulus was irrelevant to the task.

Stimuli were line drawings of common objects from two categories (vehicles and animals). Reference stimuli and comparison forms were either related (e.g., tractor and car) or unrelated (e.g., mouse and tractor). Comparison forms were degraded (i.e., contours were fragmented) so that half of them were non-nameable but the other half could still be named (see Figure 2). People were slower and made more errors when the reference and non-matching forms were related (e.g., two vehicles) relative to when the two were unrelated (e.g., vehicle and animal). The identity of the non-matching form was the source of the interference, because responses were slowed for only nameable forms. The interference occurred even though identity was irrelevant to deciding whether a form was round or oval. Boucart and Humphreys (1992) argued that global shape could not be attended to before identification was made. Identity must have been available using local information because the global shape (either round or oval) was insufficient for identification.

Firm conclusions regarding local or global precedence cannot be drawn from Boucart and Humphrey's (1992) findings, because both local and global features were disrupted

by fragmented contours. Their study was not intended to investigate global precedence per se, and it is possible that degrading the stimuli simply made the global shape difficult to identify. Although the conclusion that object identification must have preceded global shape identification is congruent with the idea that local elements were processed before global shape could be recognized, this idea should be tested in a paradigm that tests both global and local decisions more directly. Moreover, according to strong global-to-local theory as instantiated in the focusing analogy, people should be able to recognize global orientation before local identity. Thus, both identity and orientation decisions are needed to test this prediction.

Most studies investigating global precedence (processing dominance and temporal precedence) have used compound letters as stimuli (Boer & Keuss, 1982, Experiment 2; Hoffman, 1980; Kinchla, Solis-Macias, & Hoffman, 1983; Miller, 1981a; Navon, 1977, 1981; Paquet, 1992; Paquet & Merikle, 1984, 1988; but see Luna, et al., 1990). Studies that have used non-alphabetic stimuli are somewhat contradictory. For example, Boer and Keuss (1982) reported that global precedence was due to post-perceptual processes, but Hughes, et al. (1984) reported that the effect was perceptual. Also, as previously mentioned, it is likely that factors influencing visual recognition differ depending whether the stimuli are simple features or complete forms (e.g., Kitterle et. al., 1993 vs. Biederman & Cooper, 1991c).

Boer and Keuss (1982, p. 365) suggested that the amount of global dominance might vary between letters and geometric forms. Moreover, there is evidence that identifying letters involves unique factors (for example; automated processes due to familiarity of

the stimuli, or related to reading) which do not apply to visual processing of non-letters (Dawson & Harshman, 1986; Dixon & Twilley, 1986; Friedman, 1980). Although some investigations of global precedence have used different stimuli than alphabet characters (e.g., Boer & Keuss, 1982; Hughes, et al., 1984; Kitterle, et al., 1993; Luna et. al., 1990) these studies have not made direct comparisons between letters and non-letters. Strong global-to-local theory assumes that global precedence is a function of the sequence of processing, which (as in the focusing analogy) is independent of the type of stimulus. Therefore, the current experiments directly compare letter and non-letter stimuli in order to test this assumption.

It should be noted that evidence that global identity is available earlier than local features is not necessarily incompatible with explanations for global dominance that include later (i.e. post-perceptual) processes (e.g., Boer & Keuss, 1982; Earhard, 1990; Lamb & Robertson, 1988; Miller, 1981a). Post-perceptual processes can explain the presence of local interference, and the attenuation of global precedence at longer exposure durations (Paquet and Merikle, 1984). However, findings of only global dominance at brief exposure durations (Paquet & Merikle, 1984) and from non-attended stimuli (Paquet, 1992; Paquet & Merikle, 1988) compromise explanations of global dominance that only consider post-perceptual stages.

Investigating the Course of Visual Processing

Results from explorations of shape and orientation identification indicate that both global identity and global orientation often affect judgments of local identity and orientation. Although the data reviewed suggest that processing of orientation and shape

information each follow a global-to-local sequence, the data are far from conclusive. Moreover, although strong global-to-local theory assumes that visual processing of global shape and global orientation should both precede processing of local shape and orientation, data relevant to the issue are sparse.

The purpose of these experiments was to investigate the relative effects of global and local visual information on decisions about shape and orientation. As pointed out above, findings from much of the previous research might be due to processes that might be peculiar to reading (cf. Friedman, 1980). As well, while previous studies have assessed relative global and local influences on identification of either shape or orientation (e.g., Hughes et al., 1984; Navon, 1977; Palmer, 1980; Paquet, 1992), the current study combines identity and orientation decisions in the global-local paradigm. Thus, the relative time course for identifying global and local shape and orientation can be explored directly for both letter and non-letter stimuli that are similar in size, luminance and complexity.

An underlying assumption in the current study is that response time reflects the availability of information. That is, if responses to global orientation are faster than those to local identity, then it will be assumed that global orientation information is available sooner than local identity. Miller (1981b) made the cogent point that there is a distinction between processes that make information available and processes that use the information. For the current purpose, it is sufficient that predictions from local-to-global and global-to-local theories would not differ if the assumption was that response times reflect either availability or use.

Stimuli in the current experiments were similar to the compound letters used by other researchers (Navon, 1977; Paquet, 1992; Paquet & Merikle, 1988, 1984). Letter stimuli were used for the purpose of replication. Geometric shapes were used that had the same dimensions as the letters to control for the possible confound with reading processes that might be associated with letter stimuli. Both global and local decisions were measured to investigate the relative effects of global and local shape and orientation at each level.

The purpose of the first experiment was to replicate the main findings of the global-local paradigm (Navon, 1977, 1981; Paquet, 1992, Paquet & Merikle, 1988) for attended stimuli, and to generalize these findings to compound, non-alphabetic stimuli. The second experiment tested whether the results regarding global precedence for identity decisions for both letters and geometric shapes also hold for orientation decisions.

In the third and fourth experiments, shape and orientation were manipulated independently, to determine whether the relative influence of each level (i.e., global or local) was the same for identity and orientation decisions for geometric shapes (Experiment 3) and letters (Experiment 4). These experiments tested whether global orientation is available before local shape, as might be expected if the visual system used a global-to-local sequence of processing.

Experiment 1

Experiment 1 was designed to replicate and extend to geometric stimuli the main findings of the global precedence (Navon, 1977, 1981; Paquet, 1992, Paquet & Merikle, 1988). First, people are faster to identify global letters than local letters, and this should be true for non-alphanumeric stimuli. Second, reaction times should be slower when

identities of global and local stimuli (letters or shapes) are different (conflicting condition) relative to when they are the same (consistent condition), and this difference should be greater for local identity decisions than for global identity decisions. That is, global identity should influence local identity decisions more than local identity influences global identity decisions. It is assumed that any differences in accuracy will be predicted by the same hypotheses as for reaction time.

Method

Subjects. Twelve female and 12 male students participated in the experiment. Participants were undergraduates from the University of Alberta who participated for course credit.

Stimuli and Design. The design was Stimulus Type (letter, geometric shape) x Decision (global, local) x Congruency (consistent, conflicting). Compound letters were large (global) upper-case E and A made up of smaller (local) upper-case Es and As; compound geometric shapes were rectangles and isosceles triangles made up of rectangles and triangles. In the consistent condition, both global and local items had the same identity (for example, global E made of local Es), and in the conflicting condition the global and local items had different identities (for example, global E made of local As). Thus, there were eight stimuli; these are shown in Figure 4. Global and local items were each approximately 1.5 times as high as they were wide. Global rectangles were approximately 2.4° high by 1.6° wide. These were made of 20 local rectangles (7 high by 5 across) that were approximately .3° by .2° visual angle. Global and local Es were

the same dimensions as the rectangles, and As and triangles had the same height and base as the rectangles.

Each subject was given two sessions for each stimulus type. During one session, subjects were asked to identify the global shape of each stimulus. During the other session they were asked to identify the local shape of each stimulus. Thus, there were four sessions, which produce 24 possible permutations. Each subject was assigned a different one of the 24 possible orders of sessions. Dependent measures were reaction time and percent correct for the decision.

Lamb and Robertson (1988) have shown that effects of global precedence can be attenuated when subjects can accurately predict the location of the local stimuli before presentation. Paquet (1992; Paquet & Merikle, 1988) also randomly varied the location of the attended and non-attended stimuli. For these reasons, and because locations of objects cannot always be predicted in the natural environment, the location of stimuli was varied. On any given trial a stimulus was shown in one of eight positions equidistant from the fixation cross. For each position, the center of the global stimulus was 25 mm (approximately 1.5° visual angle) from the fixation cross in one of eight directions. Assuming that the position directly above the fixation cross was analogous to compass direction of North, the eight positions corresponded to compass directions North, NE, E, SE, S, SW, W, and NW. Trials were blocked in groups of 32, such that on each trial, one of the eight positions was selected randomly without replacement for each of two targets (either E and A, or rectangle and triangle) and two consistency conditions. There

were six blocks for each of the four (global/local by letter/shape) sessions for a total of 192 experiment trials for each condition.

Apparatus and Procedure. Stimuli were presented on a Hewlett Packard 1304a oscilloscope with a greenish tint P15 phosphor that decays to 10% intensity at 2.8 microseconds after display offset. A plotting device developed by Finley (1985) was used to plot the figures on the oscilloscope. The intensity of the screen was constant for all experiments. Luminance of the display was measured by plotting a patch in the center of the screen, and measuring the luminance of the patch. The patch had the same number of points as a stimulus to be displayed. Because the exact number of points plotted differed as a function of the number of points used to draw each stimulus, the luminance of the display varied slightly across patterns. Measured in this way, the patch producing the highest measurement was equivalent to a consistent A and was 83 cd/m², a consistent triangle was 74 cd/m², the lowest measurement of 54 cd/m² was equivalent to the consistent E and consistent rectangle. It is important to note that the same stimuli were used for both the global and the local conditions, and so the global/local conditions were not confounded with relative luminance between stimuli.

Subjects were seated with their heads in a chin-rest so that each subject's forehead was 965 mm from the center of the screen. The chin-rest was used so that each subject's head was in a comfortable, but stable, vertical position throughout the trials.

A touch-plate was on the table in front of the subject. The touch-plate was a wooden board with a metal palm plate, two smaller metal finger plates, and a wooden strip beside each finger plate. Subjects placed their preferred hand on the touch-plate so that the

palms rested on the larger metal plate and the index and second fingers rested on corresponding wooden strips. Responses were made by touching the smaller metal plate that corresponded to either the index or second finger of the subject's preferred hand. The index finger was used to respond "E" and "rectangle" and the second finger was used to respond "A" and "triangle".

Instructions were read to the subjects before each session, and correct use of the touch-plate was demonstrated on the first session. Instructions were followed by one block of 32 practice trials. A subject began each trial by pressing a foot-switch with the foot contra-lateral to the hand used for responding. A fixation cross was displayed in the center of the screen. When the subject initiated a trial there was a short beep and a 750 ms delay. Then a fixation cross appeared in the center of the screen and was displayed for 150 ms. Stimuli were presented for 200 ms and were followed by a blank screen. If the response was incorrect, the computer sounded two short beeps to inform the subject that the response was incorrect. No auditory feedback was given if the response was correct. Practice trials were followed by six blocks of 32 experiment trials. Experiment trials followed the same procedure as the practice trials except that the stimuli were displayed for 100 ms. After an experiment session, each subject was given a few minutes' break before the next session. Each session lasted approximately 15 minutes, and all four sessions were held on the same day. The experiment (including instructions, breaks, and a debriefing) lasted approximately 1 1/2 hours for each subject.

Results

For all experiments, mean reaction times were computed using correct trials only. If a subject's reaction time (RT) on any given trial was greater than three standard deviations from the mean for that subject on that particular session, the RT was considered to be an outlier and was discarded. One reason for outliers was that a small number of responses did not register on the first touch, so that two touches were needed for one response. The same criteria was used for all experiments, and less than 2.0% of the data was discarded for any given experiment.

Mean RTs on correct trials only were analyzed using a Stimulus Type (letter, shape) x Decision Level (global, local) x Congruency (consistent, conflicting) repeated measures analysis of variance (ANOVA). Decisions were slower for letters than for geometric shapes, $F(1, 23) = 6.76$, $p < .05$, local decisions were slower than global decisions, $F(1, 23) = 77.19$, $p < .001$, and conflicting conditions were slower than consistent conditions, $F(1, 23) = 207.07$, $p < .001$. The Stimulus Type x Decision Level interaction was reliable, $F(1, 23) = 8.63$, $p < .01$. These data are shown in Figure 5. Please note that tables of dependent measures and ANOVA summaries for all experiments are also included in the Appendix. In general, there was no difference in reaction time to identify global letters relative to global shapes (362 vs. 360 ms) but subjects were slower to identify local letters than local shapes (458 vs. 412 ms), $t(23) = 3.20$, $p < .01$. Stimulus Type x Congruency, $F(1, 23) = 12.52$, $p < .01$, Decision Level x Congruency, $F(1, 23) = 82.14$, $p < .001$, and the three-way interaction $F(1, 23) = 19.71$, $p < .001$, were also reliable.

Although the difference between stimuli with respect to luminance was small, there was a possibility that luminance could have predicted RTs between particular stimuli (but not global/local conditions). This hypothesis was not supported by the data. As outlined in the methods, the luminance of the consistent A, triangle, E, and rectangle had been measured at 83, 74, 54 and 54 cd/m² respectively. The RTs for these stimuli on global decisions were 357, 353, 357 and 355 ms respectively; for local decisions, RTs were 422, 392, 413, and 384 ms.

The RT data replicated findings that global information has priority for identification of letters. Means from the interactions with congruency were tested using paired-samples *t* tests. For letter identity judgments, the predicted global interference for local decisions was obtained. That is, for local letter identity decisions, RTs were slower for the conflicting relative to consistent condition (498 vs. 418 ms), $t(23) = 10.30$, $p < .001$. There was also some local interference, however, because for global decisions, RTs were also slightly slower for the conflicting relative to consistent condition (367 vs. 357 ms), $t(23) = 2.85$, $p < .01$.

To test for global precedence, the difference between conflicting and consistent conditions was compared as a function of decision level. In accordance with the global precedence hypothesis for letter identification, global interference (i.e., local conflicting - consistent) was greater than local interference (i.e., global conflicting - consistent) for letter identification, (80 vs. 10 ms), $t(23) = 8.31$, $p < .001$. These data are shown in Figure 6.

All of the findings of global precedence with letters extended to geometric shapes. There was global interference; because RTs were slower for the local conflicting relative to consistent condition (435 vs. 388 ms), $t(23) = 12.36$, $p < .001$. Again, there was also local interference, the global conflicting was slightly slower than the consistent condition (366 vs. 354 ms), $t(23) = 4.57$, $p < .001$. In accordance with the global precedence hypothesis for geometric shapes, global interference was greater than local interference (48 vs. 12 ms), $t(23) = 7.09$, $p < .001$.

Although global precedence was found for letters and shapes, there was more global interference for letters than for shapes (80 vs. 48 ms), $t(23) = 4.74$, $p < .001$. This implies that global identity is more salient for letter than non-letter stimuli.

In general, the error data mirrored the RT data (see Figure 7). There were reliable main effects of decision level, $F(1, 23) = 9.16$, $p < .01$, and congruency, $F(1, 23) = 11.63$, $p < .01$. The Stimulus Type x Decision Level x Congruency interaction was also reliable, $F(1, 23) = 4.50$, $p < .05$. There was global interference, because more errors were made for local decisions in the conflicting relative to the consistent condition for letters (5.4% vs. 2.0%), $t(23) = 2.74$, $p < .05$, and geometric shapes (3.7% vs. 2.1%), $t(23) = 1.98$, $p < .06$. However, errors were relatively low overall, and global interference was only greater than local interference for letters (3.3% vs. 0.5%), $t(23) = 2.38$, $p < .05$.

Discussion

Global precedence was found for identification of both letters geometric shapes. Thus, these data replicate and extend the findings of previous researchers (Luna, et al., 1990; Navon, 1977, 1981; Paquet, 1992, Paquet & Merikle, 1988) and support the

hypothesis that global precedence is a general processing phenomenon and not due solely to factors confounded with reading or other letter processing.

However, whereas subjects were equally fast to make global identity judgments about shapes and letters, for local identity judgments, shapes produced faster RTs than letters. Moreover, the shape stimuli showed less global interference than the letter stimuli. Assuming that part of the effect of global precedence was due to influence at the decision level, it is possible that the global identity of a letter is more difficult to ignore than that of a shape, perhaps because letter identification is more automatic. I return to the automaticity hypothesis in the general discussion. Given that local geometric shapes seem to have been processed quickly relative to local letters, another possibility is that rapid local processing for shapes might have attenuated the effect of the output of global processing.

Experiment 2

The previous experiment confirmed that global precedence for identity decisions generalized to shapes other than letters. Experiment 2 investigated orientation decisions for the same stimuli. Orientation is often important to shape identity (e.g., square vs. diamond), whereas the identity of many letters (in particular, the A and E of the response set for these experiments) are not a function of orientation. Thus, there is reason to expect the effect of global precedence for orientation to be larger for shapes than for letters. Considering that Palmer (1980) found local and global influences on orientation decisions for ambiguous triangles, it is also possible that bidirectional interference will be found for shapes.

Method

Subjects. Twelve female and 12 male students participated in the experiment. Participants were undergraduates from the University of Alberta who participated for course credit.

Stimuli and Design. The design was Stimulus Type (letter, shape) by Decision Level (global, local) by Orientation Congruency (consistent, conflicting). As in the previous experiment, compound letters were large (global) upper-case E and A made up of smaller (local) upper-case Es and As; geometric shapes were rectangles and isosceles triangles. Global and local items were either vertical or horizontal (horizontal triangles and As pointed right). In the consistent condition, global and local items had the same identity and orientation (for example, a global vertical E made of local vertical Es), and in the conflicting condition the global and local items had the same identity, but different orientations (for example, a global vertical E made of local horizontal Es), so that the only conflict was with respect to orientation information. Thus, there were sixteen stimuli, these are shown in Figure 8. As in Experiment 1, each subject was given four sessions, blocked by decision level and stimulus type, and each subject received a unique session order from among the 24 permutations. Within each session, trials were blocked by target, congruency, and position (as in Experiment 1) and also by orientation (vertical, horizontal), so that there were 64 trials per block. Stimuli were randomized within each block in the same way as for Experiment 1.

Global and local stimuli were the same height and base as in Experiment 1. Other than orientation, the only difference was that the top few local items were moved apart

in the global As and triangles, so that the local items could be turned horizontally without overlapping.

Apparatus and Procedure. The same apparatus and procedure was used as in Experiment 1. Subjects used their index finger to respond "vertical" and their second finger was to respond "horizontal". For each session, subjects were given one block of 64 practice trials, followed by 5 blocks of 64 experiment trials.

Results

Mean RT's on correct trials were analyzed using a Stimulus Type (letter, geometric shape) x Decision Level (global, local) x Orientation Congruency (consistent, conflicting) repeated measures ANOVA. As for Experiment 1, RTs were slower for letters than for geometric shapes, $F(1, 23) = 34.54$, $p < .001$, local decisions were slower than global decisions, $F(1, 23) = 29.24$, $p < .001$, and conflicting conditions were slower than consistent conditions, $F(1, 23) = 79.91$, $p < .001$. These data are shown in Figure 9. The interaction of Stimulus Type x Decision Level was reliable, $F(1, 23) = 8.09$, $p < .01$, as was Decision Level x Congruency, $F(1, 23) = 5.81$, $p < .05$. Unlike Experiment 1, the Stimulus Type x Congruency interaction was not reliable, $F(1, 23) = 2.94$, $p < .10$, and neither was the three-way interaction $F(1, 23) < 1$. As shown in Figure 9, there was no difference in RT between letters and geometric shapes on global orientation decisions (502 vs. 486 ms), but local decisions were slower for letters (650 vs. 563 ms), $t(23) = 5.29$, $p < .001$.

Paired-samples t tests showed effects of global interference for letter stimuli. For local decisions, RTs were slower on the conflicting relative to consistent condition (666

vs. 635 ms), $t(23) = 3.19$, $p < .01$. Once again, there was some local interference; for global decisions, the RTs in the conflicting conditions were slightly slower than consistent conditions (508 vs. 496 ms), $t(23) = 2.22$, $p < .05$.

As for Experiment 1, the comparison between global and local interference was used as a measure of global precedence. These data are shown in Figure 10. Consistent with the global precedence hypothesis, there was more global than local interference on orientation decisions for letters (32 vs. 12 ms) $t(23) = 1.82$, $p < .05$ (one tailed).

As expected, there was global interference for geometric shapes. Orientation decisions were slower on local conflicting relative to consistent conditions (587 vs. 540 ms), $t(23) = 8.97$, $p < .001$. Once again, there was some local interference; for global decisions, the conflicting condition was slightly slower than the consistent condition (497 vs. 476 ms), $t(23) = 3.16$, $p < .01$. Consistent with the global precedence hypothesis for orientation information, there was more global than local interference for geometric shapes (46 vs. 21 ms), $t(23) = 2.42$, $p < .05$.

The difference in magnitude of global interference between letters and shapes was small (32 vs. 46 ms) and did not attain reliability, $t(23) = 1.70$, $p < .10$. Unlike global identity, global orientation has the same influence on local decisions for letters and shapes.

The error data showed a similar pattern as the RTs (see Figure 11). More errors were made on letters relative to shapes (5.8% vs. 4.8%), $F(1, 23) = 6.07$, $p < .05$, more errors were made on local decisions relative to global decisions (6.4% vs. 4.2%), $F(1, 23) = 6.91$, $p < .05$, the effect of congruency was reliable, $F(1, 23) = 25.56$, $p < .001$, and the

Stimulus Type x Congruency interaction was reliable, $F(1, 23) = 16.00$, $p < .001$. As evident from Figure 11, the difference between conflicting and consistent conditions was somewhat larger for shapes (6.0% vs. 3.5%) than for letters (6.5% vs. 5.1%). Importantly, paired-samples t tests confirmed that there was more global than local interference on accuracy of orientation decisions for letters (2.7% vs. 0.1%), $t(23) = 2.50$, $p < .05$ as well as for shapes (4.0% vs. 1.1%), $t(23) = 2.57$, $p < .05$. Thus, the global precedence hypothesis for orientation decisions was supported by the error data.

Discussion

The data from Experiment 2 show that global precedence is evident for orientation information. Interestingly, as shown in Figure 10, global interference was the same for letters and geometric shapes (32 vs. 46 ms, ns). In Experiment 1, there was more global interference for letters than for shapes (80 vs. 48 ms). These findings suggest that global identity has a strong influence for letters, but that global orientation is equally important for both kinds of stimuli.

It is possible that local information is subject to different influences for shapes and letters at a decision level. For example, perhaps the identity of a letter is difficult to ignore, and therefore processing of the letter name slows decisions regarding identity and orientation for local letters. In contrast, geometric shapes are usually not associated with only one name, and so decisions regarding local orientation for shapes are not slowed by processes associated with labeling. Global orientation decisions are available from approximately the same coarse representation for these letters and shapes, thus there is little difference in RT for global decisions as a function of shape.

Although interpretation of the stimulus differences is speculative, the main finding is unambiguous. Results from Experiment 2 show effects of global precedence on orientation decisions for both kinds of stimuli. These data are predicted by Navon's (1977, 1981) theory of global precedence.

Comparison of the overall results between the first two experiments indicates that orientation decisions are slower than identity decisions for both kinds of stimuli. The between-experiments comparison suggests that, contrary to a theory of global precedence such as proposed by Navon (1977, 1981), local identity information is available before global orientation, not the other way around. Experiments 3 and 4 therefore address the relative availability of global and local shape and orientation information in within-subjects designs.

Experiment 3

One purpose of Experiment 3 was to test whether orientation decisions were indeed slower than identity decisions for geometric shapes. Another purpose was to confirm that the slowing of RTs found in Experiments 1 and 2 was indeed interference from conflicting information and not due to facilitation in consistent conditions. That is, differences between consistent and conflicting conditions might be due to either facilitation or interference or both.

A neutral condition was used in Experiments 3 and 4 so that effects of facilitation and interference could be disentangled. Facilitation could be inferred if consistent conditions produced faster reaction times than the corresponding neutral conditions. If either global information interfered with decisions regarding local information, or local

information interfered with global decisions, then the neutral conditions should produce faster reaction times than the corresponding conflicting condition.

The locally neutral stimuli were a rectangle and a triangle made of circles. Globally neutral stimuli were a large circle made of local rectangles or triangles. Circles have no orientation, and so these were globally and locally neutral with respect to orientation. However, circles are geometric shapes; therefore, for identity decisions, "neutral" stimuli were only neutral with respect to the target response set (i.e., rectangle and triangle). Assuming that global information is processed first (Navon, 1977) and that the output from early processing affects later processing (Sanocki, 1991, 1993) then global circles should interfere with local identity decisions. Circles would interfere because they always conflict in terms of identity, regardless of the target response. On the other hand, if global interference is due to influences at a decision or response level, then circles might not interfere on identity decisions, because "circle" is never a target response.

Effects of neutral stimuli have been ambiguous. Paquet and Merikle (1988) found that overall RTs for letter identification were slowed when a neutral unattended stimulus was also present relative to when only the attended stimulus was shown. In experiments using only attended stimuli, RTs on neutral conditions are sometimes between those for consistent and conflicting conditions (Paquet & Merikle, 1984) and sometimes the same as consistent conditions (Navon, 1977, Experiment 3). The current experiment uses only attended stimuli; therefore, circles might interfere with identification and slow responses to identity on neutral relative to consistent conditions but responses should still be slowest on conflicting conditions.

Method

Subjects. Twelve female and 12 male students participated in the experiment. Participants were undergraduates from the University of Alberta who participated for course credit.

Stimuli and Design. Stimuli were the geometric shapes from Experiment 1 and 2, and eight neutral stimuli. The global triangles were the adjusted versions used in Experiment 2. Globally neutral stimuli were large circles made either of small triangles or small rectangles. The small shapes were either all horizontal or all vertical, and were the same dimensions as in Experiments 1 and 2. Large circles subtended approximately 2.3° visual angle. Locally neutral stimuli were a large (vertical or horizontal) triangle and rectangle made of small circles. The small circles subtended a visual angle of 0.3°. Locally neutral rectangles and triangles were the same dimensions as the global shapes in Experiment 2. Stimuli are shown in Figure 12.

There were four sessions, one for each Decision Level (global, local) x Decision Type (identity, orientation) combination. For identity decisions at a given level (global or local), stimulus shapes were consistent with respect to orientation (as in Experiment 1), or else they were neutral. Likewise, for orientation decisions, shapes were consistent with respect to identity (as in Experiment 2), or else they were neutral. Each subject was again given a unique order of sessions. Stimuli were shown in four of the positions used in the previous experiments, corresponding to compass positions NE, NW, SE, and SW. Within each session, trials were blocked with respect to target (rectangle, triangle), orientation (vertical, horizontal), congruency (consistent, neutral, conflicting) and

position; thus, there were 48 trials per block. Subjects were given 5 blocks of experiment trials per session.

Apparatus and Procedure. The same apparatus and procedure was used as in the previous experiments. Subjects used the index finger of their preferred hand to respond "rectangle" and "vertical" and the second finger to respond "triangle" or "horizontal".

Results

Mean RTs on correct trials were analyzed using a Decision Type (identity, orientation) x Decision Level (global, local) x Congruency (consistent, neutral, conflicting) repeated measures ANOVA. Results replicated findings seen across Experiments 1 and 2. Global decisions were faster than local decisions, $F(1, 23) = 30.52$, $p < .001$, and the congruency effect was reliable, $F(2,46) = 45.92$, $p < .001$. As in the previous experiments, the interaction of Decision Level x Congruency was reliable, $F(2,46) = 4.67$, $p < .05$. No interactions with decision type were reliable. The new result is that decisions were faster for identity than for orientation information, $F(1, 23) = 64.00$, $p < .001$, (see Figure 13). Mean RTs for decisions of global identity, local identity, and global and local orientation were 424, 473, 520, and 578 ms respectively.

Paired-samples t tests showed that there was global interference on identity decisions, RTs were slower on the local conflicting relative to consistent condition (500 vs. 459 ms), $t(23) = 6.96$, $p < .001$. These data replicated the findings for the geometric shapes across Experiments 1 and 2. Moreover, there was strong evidence that the effect was indeed interference, because paired-samples t tests showed that the local-conflicting

condition was slower than the local-neutral condition (500 vs. 459 ms), $t(23) = 9.25$, $p < .001$, but the local-consistent and neutral conditions did not differ (both 459 ms).

There was also local interference on global identity decisions. The global conflicting condition was slower than the consistent condition (435 vs. 412 ms), $t(23) = 3.42$, $p < .01$. As evident from Figure 13, the global-conflicting condition was minimally slower than the global-neutral condition (435 vs. 425 ms), $t(23) = 1.76$, $p < .05$ (one-tailed). The global-consistent condition was minimally faster than the global-neutral condition (412 vs. 425 ms), $t(23) = 2.69$, $p < .05$. Considering that the neutral condition was not truly neutral with respect to identity, it is possible that there was some interference from the local circles. The possibility exists that there was an effect of local interference, although the differences in RT were small in magnitude.

Again, there was evidence for global precedence on identity decisions. The difference between the local-conflicting and neutral conditions was compared to the difference between global-conflicting and neutral conditions, and found to be reliable (41 vs. 10 ms), $t(23) = 4.81$, $p < .001$. For comparative purposes (also see Paquet & Merikle, 1984) the global and local interference effects were compared in the same way as in Experiments 1 and 2, that is, in terms of the difference between the conflicting and consistent conditions for global compared to local levels. There was slightly more global than local interference for identity decisions (41 vs. 23 ms), $t(23) = 1.88$, $p < .05$ (one-tailed). These data are shown in Figure 14.

The data from orientation decisions replicated the findings for the geometric shapes across Experiments 1 and 2. There was global interference for local orientation

decisions; RTs were slower for the local conflicting relative to the consistent condition (596 vs. 571 ms), $t(23) = 2.10$, $p < .05$. Paired-samples t tests confirmed that the effect was interference because the local-conflicting was slower than the local-neutral condition (596 vs. 566 ms.), $t(23) = 4.62$, $p < .001$, but the local-consistent and neutral conditions did not differ (571 vs. 566 ms), $t(23) < 1$.

Again, there was local interference on orientation decisions; because for global decisions, the conflicting condition was slower than the consistent condition (530 vs. 513 ms), $t(23) = 2.77$, $p < .05$. The global-conflicting condition was minimally slower than the global-neutral condition (530 vs. 517 ms), $t(23) = 1.95$, $p < .05$ (one-tailed).

For orientation decisions, the difference between the local-conflicting and neutral conditions compared to that between global-conflicting and neutral conditions was found to be minimal, (31 vs. 13 ms), $t(23) = 1.60$, $p < .15$. The difference between the conflicting and consistent conditions for local compared to global levels was also in the predicted direction (26 vs. 17 ms), but also did not attain significance ($t < 1$). Thus, the RT data showed global precedence on identity decisions, but more bidirectional interference was evident for orientation information.

Errors showed the same overall pattern as the RT data (see Figure 15). There were reliable main effects of decision level, $F(1, 23) = 10.59$, $p < .01$, and congruency, $F(2, 46) = 4.28$, $p < .05$. The Decision Type x Congruency interaction was reliable, $F(2, 46) = 11.94$, $p < .01$, as was Decision Type x Decision Level x Congruency, $F(2, 46) = 4.85$, $p < .05$.

For local identity decisions, paired-samples *t* tests showed that the consistent and conflicting condition did not differ ($t < 1$). More errors were made in the conflicting relative to the neutral condition (5.1% vs. 2.7%), $t(23) = 3.34$, $p < .01$. Accuracy was also lower for the consistent relative to the neutral condition (6.1% vs 2.7%), $t(23) = 3.05$, $p < .01$. For global identity decisions, accuracy was lower for conflicting relative to the neutral condition (3.9% vs. 2.2%), $t(23) = 2.41$, $p < .05$.

Accuracy on orientation decisions showed global, but not local interference. For local orientation decisions, more errors were made in the conflicting relative to consistent condition (7.4% vs. 4.2%), $t(23) = 2.80$, $p < .01$, and in the conflicting relative to neutral conditions (7.4% vs. 5.1%), $t(23) = 3.38$, $p < .01$. For global orientation decisions, no differences were reliable between consistent, neutral, or conflicting conditions (3.9%, 5.0%, and 4.4% error respectively).

Importantly, there was more global than local interference on orientation decisions, whether the comparisons were between global and local levels for conflicting relative to neutral (2.3 vs. -0.6%), $t(23)$ 3.08, = $p < .01$ or relative to consistent conditions (3.2 vs. 0.5%), $t(23) = 2.20$, $p < .05$. Thus, the error data support the global precedence hypothesis for orientation.

Although differences between the RT means were not statistically significant in the present experiment, the differences were in the direction predicted and were consistent with the other experiments. I conclude that the RTs generally support the global precedence hypothesis, but that it is possible that there was a slight speed accuracy trade-off that attenuated some of the global interference on RTs for orientation decisions.

Discussion

As expected, the data from Experiment 3 provided further evidence for global precedence for identity decisions about geometric shapes. The error data supported the global precedence hypothesis for orientation decisions, but once again there was local interference on RTs. Moreover, in contrast to predictions of some global-to-local processing theories (e.g. Navon, 1977), both local and global orientation decisions for geometric shapes are slower than identity decisions. The data indicate that global identity is available first, then local identity, followed by global and then local orientation. Figure 13 shows that this sequence holds across congruency conditions. Experiment 4 tested whether this sequence also holds for letters.

Experiment 4

Unlike many geometric shapes, the orientation of most letters is unambiguous. Moreover, with few exceptions (e.g., p and d), a letter can be identified by its local features rather than by its global orientation. Therefore, decisions regarding identity of the A and E in these studies can be independent of orientation information and vice versa. It is thus quite possible that the sequence of availability found in Experiment 3 will not hold for letters. The purpose of Experiment 4 was to test whether findings from Experiment 3 would generalize to letters, or whether the relative availability of shape and orientation information would depend on the category of stimuli.

Method

Subjects. Twelve female and 12 male students participated in the experiment. Participants were undergraduates from the University of Alberta who participated for course credit.

Stimuli and Design. The design was the same as that for Experiment 3. Stimuli were compound letters E and the adjusted A from Experiments 1 and 2, and eight neutral stimuli. Neutral stimuli were global circles made from local horizontal and vertical Es and As and global horizontal and vertical Es and As made from circles. Large and small As were the same dimensions as corresponding triangles in Experiments 2. Circles were the same dimensions as those in Experiment 3. Stimuli are shown in Figure 16.

Apparatus and Procedure. The same apparatus and procedure was used as in the previous experiments. Subjects used the index finger of their preferred hand to respond "E" and "vertical" and the second finger to respond "A" or "horizontal".

Results

Mean RTs on correct trials were analyzed using a repeated measures ANOVA in which the factors were decision type (identity, orientation), decision level (global, local) and congruency (consistent, neutral, conflicting). Results replicated most of the findings of the previous experiment. Decisions were faster for identity than orientation, $F(1, 23) = 108.99$, $p < .001$, global decisions were faster than local decisions, $F(1, 23) = 90.61$, $p < .001$, and the congruency effect was reliable, $F(2,46) = 67.83$, $p < .001$. As in the previous experiments, the interaction of Decision Level x Congruency was reliable,

$F(2,46) = 31.95$, $p < .001$. As evident from Figure 17, the difference between consistent and conflicting trials was smaller on global decisions than local decisions.

The Decision Type x Decision Level interaction was reliable, $F(1, 23) = 11.40$, $p < .01$, as was Decision Type x Congruency $F(2,46) = 7.06$, $p < .01$, and the three-way interaction $F(2,46) = 5.53$, $p < .01$. Essentially, there was more global interference for decisions of identity than orientation. Mean RTs for decisions of global identity, local identity, and global and local orientation were 398, 479, 474, and 619 ms, respectively.

In contrast to the findings for shapes (Experiment 3), in which no interactions with Decision Type attained significance, in the current experiment all interactions with Decision Type were reliable. One interpretation of these data is that identity and orientation decisions with letters involve processes that are not independent across global and local levels. Another possibility is that the information was extracted independently, but that interactions were due to influences at the decision level, when relevant orientation and identity information was selected.

Once again, there was global interference on identity decisions. Paired-samples t tests showed that RTs were slower on the local-conflicting relative to the consistent condition, (535 vs. 451 ms), $t(23) = 11.53$, $p < .001$, and also in the conflicting relative to the neutral condition (535 vs. 450 ms), $t(23) = 13.99$, $p < .001$. For global decisions, the conflicting condition was slower than the consistent condition, (410 vs. 391 ms), $t(23) = 3.76$, $p < .001$, and the conflicting and neutral conditions also differed (410 vs. 394 ms), $t(23) = 2.86$, $p < .01$. These data replicated the findings for the letters in Experiment 2.

Global precedence was found for identity decisions. Paired-samples *t* tests showed that the comparison between global and local interference was reliable whether the difference was between conflicting and consistent conditions (84 vs. 19 ms), $t(23) = 6.58$, $p < .001$, or conflicting and neutral conditions (85 vs. 16) ms, $t(23) = 7.89$, $p < .001$.

There was evidence for global interference on orientation decisions. Paired-samples *t* tests showed that RTs for the local-conflicting condition was slower than those for the consistent condition (659 vs. 620 ms), $t(23) = 3.18$, $p < .01$, and RTs were slower for the local-conflicting relative to the neutral condition (659 vs. 578 ms), $t(23) = 6.54$, $p < .001$.

Surprisingly, for orientation judgments, RTs on the local consistent condition were slower than on the local neutral condition (620 vs. 578 ms) and this difference was reliable, $t(23) = 2.87$, $p < .01$. It is possible that the time to process global orientation interferes with processing of local orientation, whether the global orientation is consistent or conflicting. It is also possible that reaction time for the local-consistent condition was inflated because it was more difficult to parse the local shapes in the consistent condition relative to the neutral condition. Whatever the reason, the consistent condition was slower than the neutral condition; therefore, consistency did not produce facilitation.

There also was a small amount of local interference. For global orientation decisions, the conflicting condition was slower than the consistent conditions (479 vs. 471 ms), and the difference was reliable, $t(23) = 2.12$, $p < .05$. However, neither condition differed from the neutral condition (473 ms).

There was global precedence for RTs on orientation decisions (see Figure 18). Paired-samples *t* tests showed that the comparison between global and local interference was reliable whether measured by the difference between conflicting relative to consistent conditions, (39 vs. 8 ms), $t(23) = 2.35$, $p < .05$, or conflicting and neutral conditions (80 vs. 6 ms), $t(23) = 6.34$, $p < .001$.

As expected, the error data reflected RTs (see Figure 19). There were reliable main effects of decision type, $F(1, 23) = 35.76$, $p < .001$, decision level, $F(1, 23) = 15.46$, $p < .001$, and congruency, $F(1, 23) = 12.90$, $p < .001$. There were also reliable interactions of Decision Type x Decision Level, $F(1, 23) = 8.94$, $p < .01$, and Decision Level x Congruency, $F(1, 23) = 5.22$, $p < .01$.

The error data provided additional evidence for global precedence on identity decisions, because there was more global interference than local interference whether the conflicting conditions were compared to consistent (4.9 vs. 0.5%), $t(23) = 2.47$, $p < .05$, or neutral conditions (4.3 vs. 0.9%), $t(23) = 2.36$, $p < .05$.

For orientation decisions, a comparison of conflicting and neutral conditions showed evidence for global precedence, (4.4 vs. 1.1%), $t(23) = 2.40$, $p < .05$. The comparison of conflicting and consistent conditions was in the appropriate direction (differences of 2.9% vs. 0.9% error for global and local interference respectively) but was not reliable, $t(23) = 1.09$, $p < .29$.

Discussion

Results from Experiment 4 confirm that identity information is available before orientation. As in Experiment 3, decisions of global orientation are no faster than those

for local identity. It is evident from Figure 17 that RT for local identification is likely inflated due to global interference; nevertheless, the overall sequence of availability is the same for letters as for geometric shapes. That is, identity is available before orientation, and especially, global orientation does not precede local identity.

General Discussion

The main findings of these experiments can be summarized as follows. Global decisions were consistently faster than local decisions, whether the task was identification of shape (Experiments 1, 3, and 4) or orientation (Experiments 2, 3, and 4). Furthermore, global identity influenced time for local shape identification more than local identity influenced time for global shape identification (i.e., global precedence). Similarly, Experiments 2, 3, and 4 illustrate that global orientation influenced time for local orientation decisions more than local orientation influenced global decisions. Thus, there was global precedence for both shape and identity decisions about the same stimuli. Neutral conditions (Experiments 3 and 4) provided evidence that although conflicting information interfered with decisions, consistent information did not facilitate them. Overall, the evidence is strongly in favor of global precedence, but local interference was usually present as well.

Global precedence for shape identification is not solely due to processes that are unique to letter identification because the effect is also evident with geometric shapes (Experiment 1 and 3). However, the overall response time for global and local decisions was influenced by stimulus type. Local decisions were slower for letters than shapes whether the decisions were identity (Experiment 1) or orientation (Experiment 2), and

there was more global interference on identity decisions for letters than shapes (Experiment 1, see also Figures 17 and 18).

The current experiments support the global precedence hypothesis for visual processing (Navon, 1977, 1981). The strong evidence for priority of global information is contrary to predictions from local-to-global theories (including Biederman, 1987; Treisman, 1988). The current findings thus add to the converging evidence that influences from global identity and orientation should be incorporated in theories of visual recognition.

Paradoxically, these data do not support most theories used to account for global precedence. According to most global-to-local theories, including Navon's (1977, 1981) and the focusing analogy (Bouma, 1971; Lupker 1979), global orientation should be available from an initial blob-like representation before local identity is available (see also Humphreys, 1983, 1984; Marr & Nishihara, 1978). The current data indicate that identity decisions are faster than orientation decisions (Experiments 3 and 4), and surprisingly, that local identity decisions can be made before global orientation decisions. Moreover, this sequence held even though global precedence was evident for both identity and orientation decisions. The finding that identity decisions precede those for orientation is compatible with theories in which object recognition is independent of viewpoint (and therefore, global orientation; for discussion see Biederman, 1987; Marr, 1982). The findings of global precedence combined with the fact that local shape identity is available prior to global orientation, are incongruent with strong global-to-local theories of visual processing (Navon, 1977, 1981), and with theories of object

recognition that do not allow for global precedence (e.g., Biederman, 1987; Hummel & Biederman, 1992; Treisman, 1988).

The finding that judgments of global orientation are slower than those of global and local identity sheds a new light on Boucart and Humphreys' (1992) data. They found that judgments about whether two shapes were round or oval were influenced by the identity of a third stimulus, even though identity was irrelevant to their task. It is possible that rather than identifying global shape per se, their subjects might have identified global orientation. The global shapes were vertical (almost round) and horizontal (oval) ellipses. Boucart and Humphreys (1992, p. 804) point out that the global shape was identified by the orientation of the main axis of the forms, and suggest that "the task could be performed only by taking into consideration the orientation of the main axis" (p. 804). It is possible that Boucart and Humphreys (1992) were correct in assuming that their subjects made global orientation decisions, but were incorrect in assuming that global shape and orientation would become available at the same time. Thus, the identity of the objects was likely to have been available to their subjects before global orientation decisions could be made, but a global orientation decision should not be equated with a global shape decision.

There are several ways to explain why orientation decisions were slower than identity decisions. One way that can partially reconcile these data with Treisman's (1988) theory is to assume that identity decisions were based on feature detection, but that orientation decisions involved more complete processing. That is, the A and the triangle could be discriminated from the E and the rectangle by detecting a sloping line,

but for these stimuli, both global and local orientation was interpreted from feature conjunctions (for example, a vertical A contains no vertical lines), and identifying conjunctions is believed to require attentive (and hence, time consuming) processes (Treisman, 1988). Unfortunately, Treisman's (1988) theory still does not explain why local decisions were slower than global decisions, nor does it account for global precedence.

It is also possible that the orientation of the stimuli in the current experiments was difficult to determine because aspect ratios are less discriminable than diagnostic features. Davi and Proffitt (1993) suggested that orientation decisions for two-dimensional shapes are made using the base and an axis orthogonal to the base. Thus, the relatively slow orientation decisions might be explained in terms of the time needed to identify a base and axis of the current stimuli relative to the time needed to simply discriminate two shapes. This interpretation predicts that response times for orientation decisions could be reduced by increasing the aspect ratio or making the base more recognizable (e.g., Davi & Proffitt, 1993).

Another plausible explanation for why orientation decisions were slow is that the orientation of most shapes is interpreted (often arbitrarily), and not simply determined by the orientation of component features. For example, although the horizontal rectangles in the current study were labeled horizontal according to aspect ratio, a drawing of a bus (which is also globally rectangular) would probably be labeled vertical even if the main shape of the bus was a horizontal rectangle. A related explanation is that the additional time for orientation decisions was due to unfamiliarity with retrieving

labels for orientation compared to those for identity, and not as a function of relative time to process or combine shape and orientation information. Although subjects were instructed to respond only to orientation, they did not need to explicitly label it. Therefore, these explanations imply that label retrieval is mandatory for orientation decisions, and that the slow orientation decisions were entirely due to a post-perceptual effect at the decision level, and not visual recognition per se. These are both empirical issues.

All of the above explanations about why orientation decisions were slower than identity decisions are compatible with the idea that orientation is derived from a representation of shape (Rosenfeld, 1986; Marr & Nishihara, 1978), and that global and local shape are represented before processes that derive orientation are completed. An alternative possibility is that determining the orientation and identity of an object involves independent processes, but (for one or more reasons mentioned above) the processes used to identify orientation take longer than those used to identify shape. Either way, global orientation is available before local orientation, and therefore global orientation influences local orientation decisions. A prediction that follows is that cues to global orientation do not prime shape identification, even if global orientation predicts identity. There is some support for this prediction (Sanocki, 1993, Experiment 1b; but see Humphreys & Quinlan, 1988, Experiment 4).

I conclude that visual recognition generally follows a global to local sequence, and the current data underscore the importance of global information for recognition. However, the presence of some local interference in the current experiments, and

evidence that precedence of global information can be attenuated by factors including attention, strategy, and practice (Earhard, 1990; Earhard & Walker, 1992; Lamb & Robertson, 1988; Paquet, 1992) indicates that some global and local information is processed simultaneously (Miller, 1981a). It is likely that the global precedence effect is partly due to post-perceptual processes, when task-relevant global and local shape and orientation information is sorted out (see also, Boer & Keuss, 1982; Miller, 1981a; Paquet, 1992).

In the following discussion I first outline two assumptions that underlie explanations of global precedence. One assumption is that global information is processed more quickly than local information (rapid-global), and the other is that channels used to process global information are stronger than those used for local information (relative strength). Second, I explain details of a model to account for the current data. Third, I argue that qualitative differences at the stimulus level probably contribute to the difference in strength between global and local information channels.

Rapid-global

According to the rapid-global assumption, global information is accumulated initially and rapidly, and local information is accumulated later and more slowly (Navon, 1977, 1981, 1991). A model that relied on this assumption would be a general feature model (for discussion, see Sanocki, 1991, 1993), in which global features initially predominate. Navon (1981) points out that the idea of rapid global processing does not preclude the notion of simultaneous processing of global and local information; the point is that global processing is initiated first, and the output is available sooner.

One explanation of global precedence based on this assumption is in terms of spatial frequency. For any given compound stimulus, global features are specified by lower spatial frequencies than local features. There is evidence that low-spatial frequencies are processed more quickly than high-frequencies (Breitmeyer, 1975; Breitmeyer & Ganz, 1976, Watt 1988), and that low-spatial-frequency channels can inhibit activity in high-spatial-frequency channels (Hughes, 1986; Kitterle et al., 1993). However, although a large portion of the global precedence effect can be explained in terms of spatial frequency (Hughes, et al., 1990; Hughes, et al., 1984; Kitterle, et al., 1993), Navon (1977, pp. 379-380) points out that if spatial frequency accounted for all of the difference in processing, then the global-precedence effect should be tied to the absolute size of the stimuli, and not the relative size of the global-local components.

It would be parsimonious to adopt only the rapid-global assumption. However, Sanocki (1991, 1993) argues that even if global features accumulate and preponderate early in processing, they would not necessarily affect the efficiency of later processing. Unfortunately, by itself, the rapid-global assumption has difficulty explaining why any local interference would be present. Moreover, it has difficulty in predicting differences in magnitude of global interference between letters and shapes, and in predicting why local identity would be available before global orientation. Rapid-global processing would not explain why the presence of global interference can depend on global shapes being members of the target response set (Paquet 1992; Paquet & Merikle, 1988); this dependency was illustrated in the current experiments when global circles did not interfere with local identity decisions.

A rapid-global account can be made viable if it accommodates a mechanism to account for evidence that global precedence is subject to strategic control (e.g., Lamb & Robertson, 1988; but see Navon & Norman, 1983; Miller, 1981a) and demands on attention (Ward, 1982; Miller, 1981a). Some researchers (Davis, 1981; Watt, 1988; Watt & Morgan, 1985) have argued that spatial frequency filtering is subject to strategic control, and Kitterle et al. (1993) suggested that low-spatial-frequency channels might play a role in capturing and directing attentional processes. A possible mechanism is one by which paths of global and local information are subject to changes in strength or weight in processing as a function of attention (e.g., Cohen, Dunbar, & McClelland, 1990; Paquet, 1992). The assumption of relative-strength will be discussed next.

Relative-strength

The idea of relative-strength can accommodate the assumption of relative-speed, in that processing of global information might be initiated first, but is not completed before local information is processed. However, accounts based on relative-strength do not necessarily incorporate the rapid-global assumption (e.g., Paquet, 1992). According to the relative-strength assumption, global and local information is accumulated using different input channels and is processed in parallel, but the global and local paths differ in importance (i.e., priority with respect to post-perceptual decisions) and/or influence (i.e., strength).

Mechanisms for implementing path strength depend on the particular instantiation (e.g., Cohen, et al., 1990; Paquet, 1992), and include processing resources (Sanocki, 1993), attenuating filters (Paquet, 1992; Treisman, 1988), and variable activation weights

(e.g., Cohen, et al., 1990; Paquet, 1992; see also Mewhort, Braun, & Heathcote, 1992). Two main assumptions are that global channels are usually "stronger" than local channels, and that the strength can vary (Paquet, 1992) as a function of attention, strategy, practice, and task demands. Global and local interference is a function of the relative strength of the global and local paths at a response-selection stage.

The assumption that global channels are usually stronger than local channels is important (Miller, 1981a; Paquet, 1992). If the strength of global and local channels is the same, and interference is simply a function of competing responses, then local congruent (i.e., no competition) conditions would be faster than global conflicting (i.e., competitive) conditions.

The assumption of relative strength (e.g., Paquet, 1992) can explain attenuation of-global-interference, and the presence of local interference as a function of attention, practice, and/or strategy. The idea of relative strength is compatible with the rapid-global assumption, but the emphasis is on relative strength (i.e., more global influence during processing) rather than relative speed (i.e., global processing is merely faster) to explain global interference.

According to Paquet's (1992) model, global and local information is input through separate channels, and these channels are filtered. Attended and unattended objects are filtered by an object filter, and the global and local aspects of both kinds of objects are filtered by a scale filter. Incoming signals have a pre-filter activation level that is determined by the task (thus, subject to strategic control), and the activation level is attenuated by the object and scale filters. The filters are directed by attention, and

response selection is competitive, based on the relative strength of post-filtered signals (as in Cohen, et al., 1990). Thus, under global directed attention, local information is attenuated by the scale filter but global information is left intact. Similarly, under local directed attention, global information is attenuated. Paquet's (1992) model needs two modifications in order to account for stimulus differences and processing of orientation information. A revised model can account for the findings that local responses were slower for letters than shapes but global responses were the same, that there was more global interference for letters than shapes on identity decisions, and that orientation decisions were slower than identity decisions.

A model to explain the current data

The current data can be explained in terms of Paquet's (1992) model, with two modifications. As in Paquet's (1992) model, I assume that the amount of global and local interference is a function of both the level of pre-filter activation and the amount of attenuation from the scale filter. I also assume that initial activation is higher for global than local information, and that global channels are stronger than local channels. Therefore, overall, global information is less attenuated (i.e., is "stronger") than local information and there is more global than local interference at the response selection stage. The first modification of the model is that subjects are less able to attenuate the global identity of letters than they are to attenuate the global identity of geometric shapes. Some reasons for this will be outlined below. This modification accounts for why, on local identity decisions, there is more global interference for letters than for shapes.

In Paquet's (1992) model, global and local channels are attenuated by a scale filter, and the output is subsequently processed. The second modification I propose is that the output of the scale filter follows two paths. One path is for identity processing, and this path activates a response to shape. A second path is for orientation processing, and activates a response to orientation. Thus, the identity and orientation paths each output to a response level, at which discrete responses have pre-activation levels and a threshold for firing. This modification can account for how identity decisions can be slower than orientation decisions.

In terms of the revised model, identity processing for letters always occurs because it is never completely attenuated. Thus, higher post-filter activation levels for letters than geometric shapes produce more global interference on local responses from letter identity than from shape identity. A plausible reason why global letter identity is not completely attenuated, even if letter identification is not automatic (e.g., Dixon & Twilley, 1986; Friedman, 1980), is that alphanumeric shapes might be more strongly associated with shape-specific labels than are geometric shapes. This is because letters have unique labels, but different labels are often given to the same geometric shape (e.g., a rectangle might be labeled "shelf," "table-top," or "doorway"). Thus, the reason why local identity decisions for letters were relatively slow, and why there was more global interference on local identity decisions for letters than for geometric shapes was because global letter names were difficult to ignore. On the other hand, the time to make global identity responses did not differ as a function of stimulus type because global channels are only attenuated when subjects are responding to local features. The relative levels

of competition from identity responses to local features were the same between letters and shapes.

The magnitude of interference from global identity was less for geometric shapes than for letters. This is likely because geometric shapes do not always elicit unique labels the way letters do. Nevertheless, "rectangle" and "triangle" are familiar labels for familiar shapes. It is quite possible that global interference would be lessened if unfamiliar shapes were used and if the shapes did not have a familiar label. If so, then global precedence might still be important for recognition of familiar objects in the everyday world, but might not apply to visual processing of unfamiliar or unknown stimuli (for example, as found in a novel or unfamiliar environment).

Besides interfering with local letter identity decisions, processing of global letter identity also produced slower responses to the local orientation of letters, whether the orientation condition was consistent or conflicting. However, Experiment 2 showed that interference from global orientation was the same for letters and geometric shapes; this must be because the initial activation, response thresholds, and amount of attenuation of orientation information was the same between stimulus types.

There was no interference from circles on orientation decisions. This is because circles have no orientation; therefore, orientation was not processed for circles. There was also low initial activation for responses to circles, because they were never included in the response set.

In summary, the differences in global interference between stimuli were found on identity decisions, but local decisions were slower for letters than shapes on both kinds

of decisions. Although the differences in performance between stimulus conditions in the current study might be spurious (for example, the geometric stimuli were closed and the letter stimuli were open shapes), similar differences have also been reported within the same category (e.g., letters, Lamb & Robertson, 1988). I concur with the suggestion that the issue of stimulus differences should be investigated further (Lamb & Robertson, 1988).

The second modification of the model was to introduce a path for orientation processing. If it is assumed that orientation and identity are processed independently, then separate inputs and separate paths would be used for identity and orientation. That is, identity and orientation would be processed in parallel, and each path would accept output from the scale filter. The relative speed of identity and orientation decisions in the current experiments could be expressed either in terms of relative path strength or lower initial activation levels for responses to orientation. If it is assumed that orientation is dependent on identity processing, then identity processing would precede orientation processing, but the paths would be connected. In this way, orientation decisions would be slower than identity decisions due to additional processing time needed for orientation.

Whether or not paths for identity and orientation should treated as independent in the model might be addressed empirically. Subjects could be asked to respond to identity (e.g., letter A) in one condition, to orientation (e.g., vertical) in a second condition, and to a conjunction (e.g, vertical A) in a third condition. The RT and probability correct for responses to identity and orientation independently and conjoined could be used to test

assumptions regarding independence. For example, if the probability correct in the conjunction condition is not equal to the product of the probabilities correct for identity and orientation alone, then the two types of information should not be treated as independent in the model (for a comprehensive discussion, see Ashby & Townsend, 1986).

One reason for the assumption that global and local channels differ in strength (Paquet, 1992) is that there are qualitative differences between global and local information (Earhard, 1990; Navon, 1977; 1981; Palmer, 1980; Paquet, 1992). Earhard (1990; Earhard & Walker, 1985) and others (e.g., Sanocki, 1993) have argued that there are ecological reasons why global information has priority for visual recognition. Moreover, most interpretations of global precedence include the idea that global and local information are qualitatively different (e.g., Navon, 1977; Palmer, 1980; Paquet, 1992; Sanocki, 1993). Qualitative differences might be manifested in a number of ways. I suggest that the importance of qualitative differences at the stimulus level might be underestimated.

In general, global aspects of compound stimuli are degraded relative to local aspects. That is, whereas the global features in the current stimuli are made of discontinuous units of varying width, local features are continuous line segments. Despite the fact that global aspects are made up of broken line segments, people can consistently identify global shape and orientation more easily than local aspects.

An implication of these differences at the stimulus level is that qualitatively different mechanisms might be used to perceive global and local levels. Many researchers

(Grossberg & Mingolla, 1985; Kellman & Shipley, 1991; Ramachandran, 1992; Ullman, 1984) have proposed processes that include grouping, contour completion, and "filling-in" to account for various situations in which continuity is perceived from discontinuous displays. Processes that group units together and "fill in" the gaps might not be necessary for detection of local features. In contrast to local features, it is likely that global features in compound stimuli invoke processes loosely referred to here as grouping and boundary completion in order for them to be perceived.

It might be argued that grouping and completion processes either implies that global features should be processed more slowly than local features, or limits generalization from compound stimuli. However, in contrast to this intuition, it can be argued that these processes contribute to the speed with which global shape is usually identified (Kellman & Shipley, 1991), especially if the processes are pre-attentive (Donnelly, Humphreys, & Riddoch, 1991). In the natural world there are many cases where objects are partly occluded, yet Kellman and Shipley (1991) point out that people readily perceive unity and boundaries of partly occluded objects. Moreover, researchers (Donnelly, Humphreys, & Riddoch, 1991; Grossberg, 1987a, 1987b; Grossberg & Mingolla, 1985; Kellman & Shipley, 1991, 1992) have repeatedly argued that processes by which continuity is perceived across broken boundaries are fundamental to ordinary object perception in the natural world.

One prediction is that global interference would be stronger for compound stimuli in which only the global aspects depended on grouping and completion, than for stimuli that either have continuous global features, or discontinuous local features. This

hypothesis might be explored if continuity was controlled across global and local aspects (cf. Hoffman, 1980).

It is important to note that the idea of the relative importance of global information is not dependent on the presence of discontinuous features. Sanocki's (1991, 1993) evidence for the effectiveness of global primes and his constituency model (Sanocki, 1993) were established using unbroken line drawings. Like Navon (1977), Sanocki (1993) concluded that global information was important in early processing. However, Sanocki's (1993) priming study showed that the relative contribution of global and local information reverses over time but Navon's (1991) experiments showed that the global advantage did not diminish over time. Sanocki (1993) speculated that the different paradigms might invoke different processes. The different paradigms also use different stimuli, and if the compound stimuli used by Navon (1991) and the current experiments invoke different processes than do unbroken stimuli, then a complete understanding of global precedence effects will include an understanding of both types of processes.

Conclusions

The present data confirm that global precedence is a phenomenon of visual processing in general, and not an artifact of processes associated with letter identification. However, there was more global interference for letters than for shapes, especially on identity decisions. Also, responses to letters were slower than to shapes, but only for local decisions. Results indicate that global precedence is evident for both identity and orientation information. However, contrary to global-to-local theories which posit an initial blob-like representation from which global identity and global orientation

can be determined before local shape is available, the current data indicate that global and local identity are available prior to global orientation. I discussed alternate explanations for the finding that global orientation decisions were slower than local identity decisions, and explained details of a model that could account for the data. Finally, I argued that global features in compound stimuli are qualitatively different from local features, and processes such as grouping and completion might contribute to global processing.

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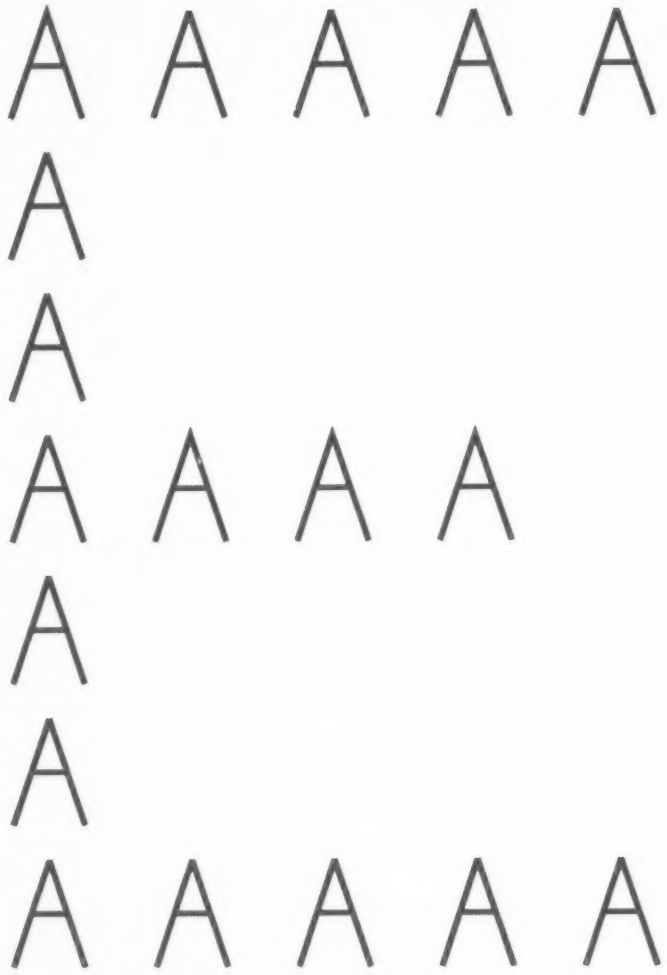
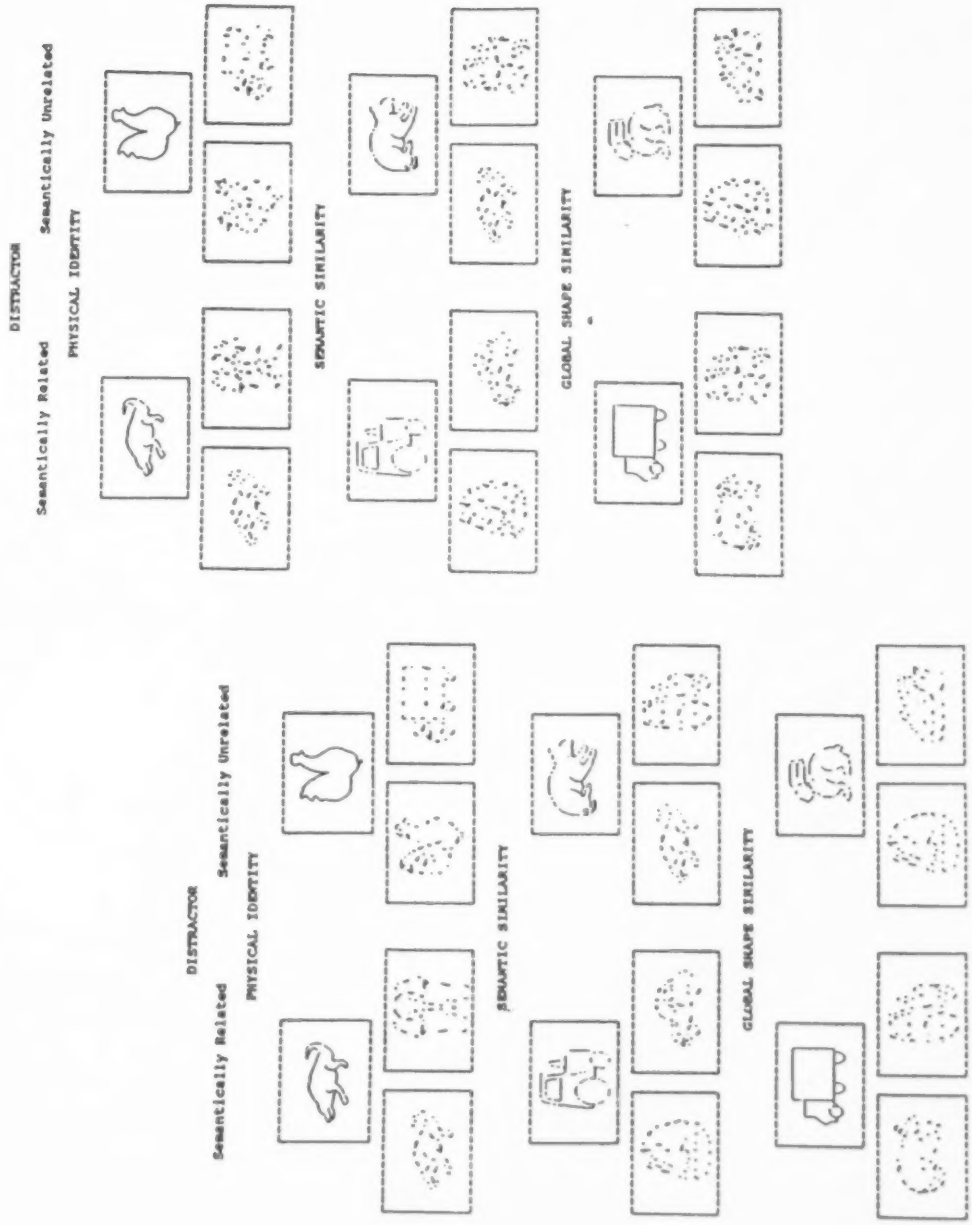


Figure 1. Example of a typical compound stimulus. The global E is made up of local As.



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Strasbourg, 16 Mai 1994

From Dr. Muriel Boucart
Hopitaux Universitaires de Strasbourg
INSERM (U405)
Département de Psychiatrie I
67091 Strasbourg Cedex
france.

By this letter I give my permission to Mr David Hall to reproduce for his dissertation two of the figures (p.787-788) of the paper "Global shape cannot be attended without object identification" by M. Boucart and G.W. Humphreys published in the Journal of Experimental Psychology: Human Perception and Performance vol. 18 in 1992.

Yours sincerely,

Muriel Boucart

M. Boucart

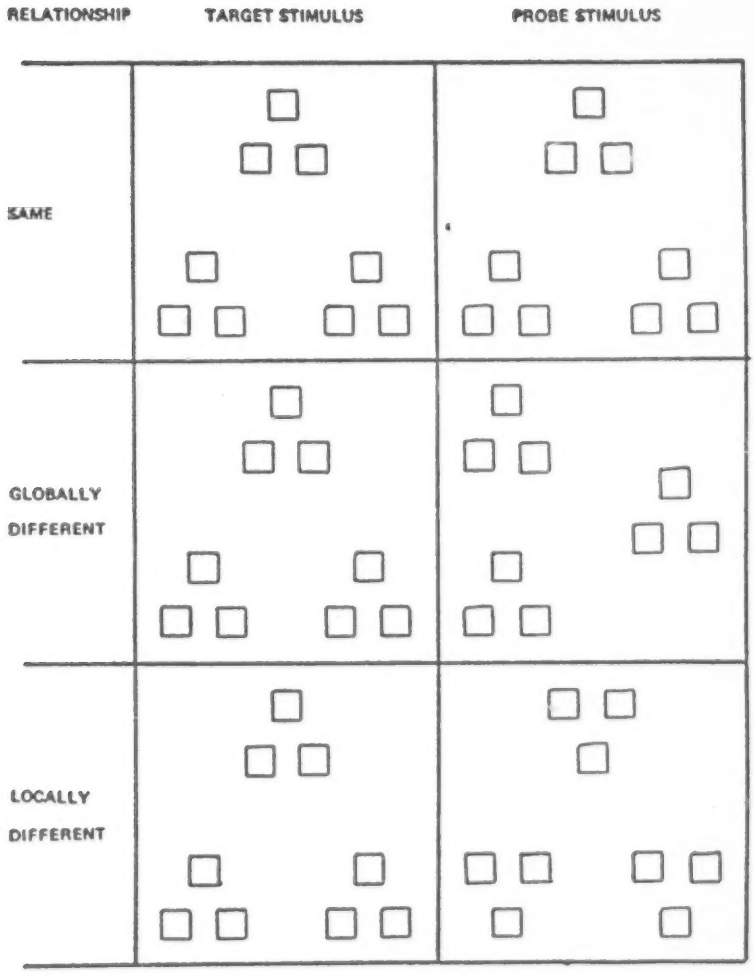

Figure 3. From "Forest Before Trees: The Precedence of Global Features in Visual Perception" by D. Navon, 1977, Cognitive Psychology, 9, p. 373. Copyright 1977 by Academic Press. Reprinted by permission.

DAVID HALL, PHONE: 403-492-5845, EMAIL: dave@psych.ualberta.ca

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Dear Sir:

I would like permission to reproduce one of the figures from the paper by Navon, D. (1977), entitled Forest before trees: The precedence of global features in visual perception. Cognitive Psychology, 9. The figure in question is Figure 9 (p. 373), showing the stimuli for Experiment 4.

With your permission it will be reproduced in the text of my dissertation and in a forthcoming paper. The Faculty of Graduate Studies and Research requires that a letter of permission be included in the thesis.

Yours sincerely,

David Hall

cc. Dr. David Navon

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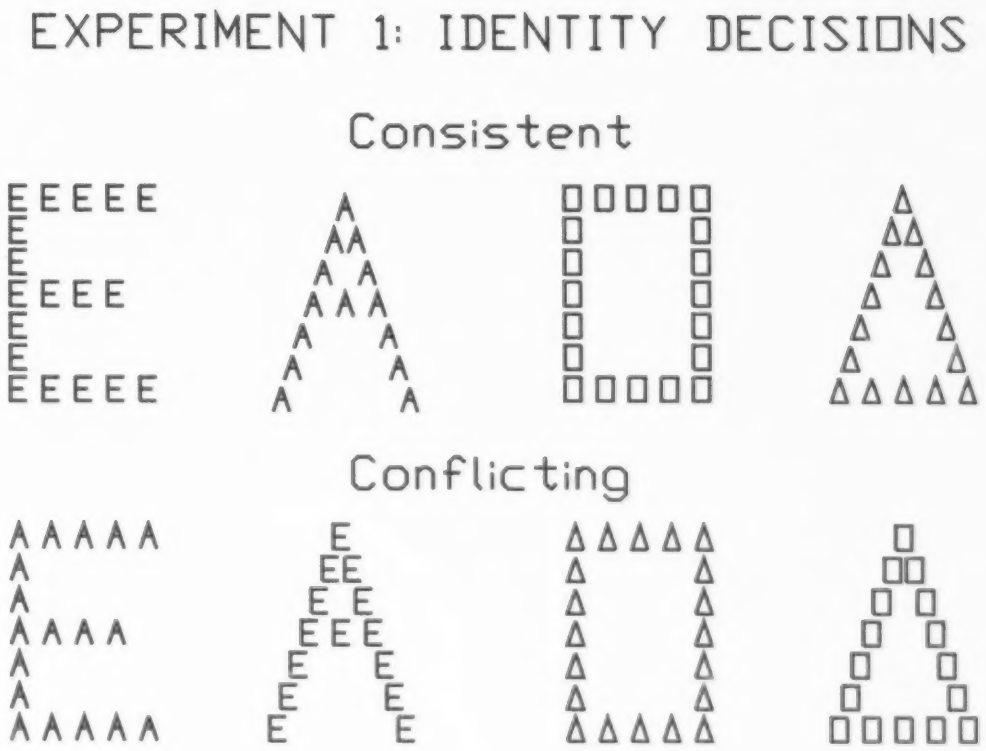

Figure 4. Letters and geometric shapes used in Experiment 1. In the top row, global and local identities are the same (consistent), in the bottom row, identities are different (conflicting).

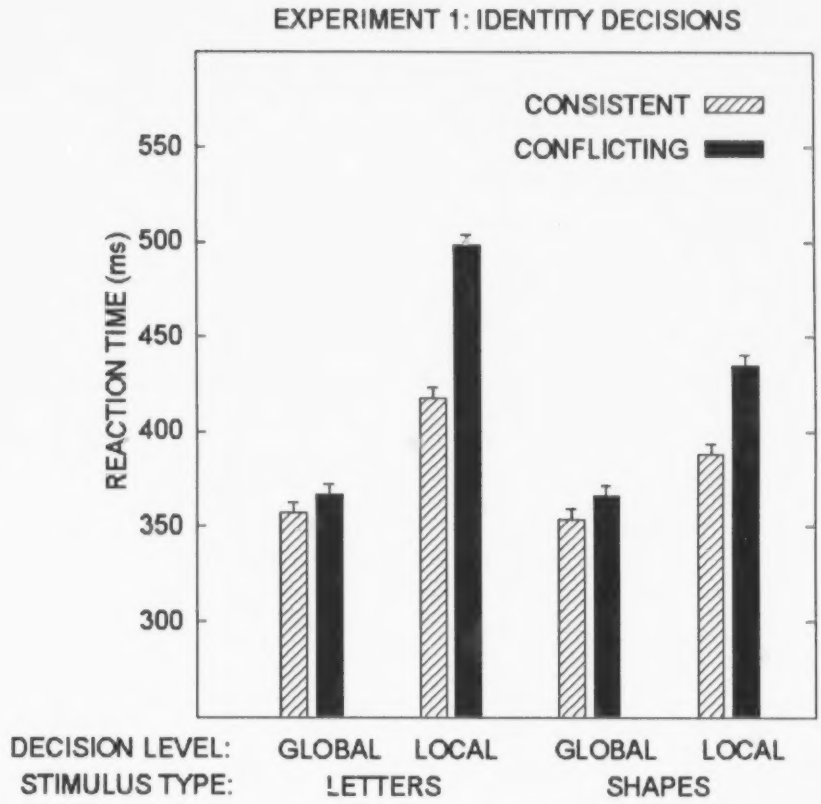

Figure 5. Mean RTs of correct trials from Experiment 1. Confidence intervals (+/- 5.50 ms) are computed using the MSe from the interaction, as recommended by Loftus and Masson (1993).

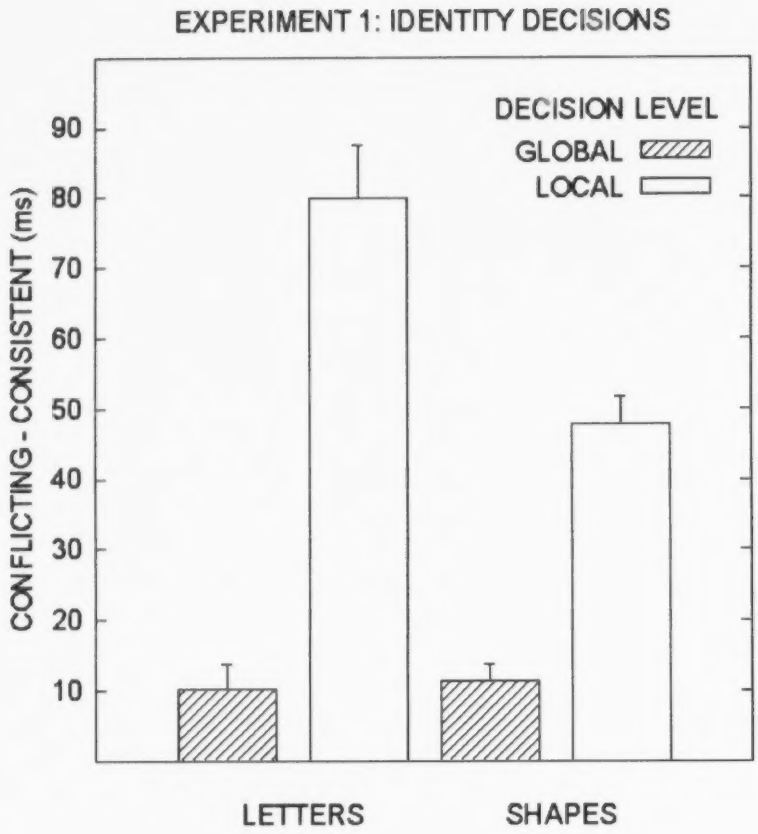

Figure 6. Global and local interference effects from Experiment 1. Global interference is the difference between the local-conflicting and local-consistent conditions. Local interference is the difference between the global-conflicting and global-consistent conditions. Standard error bars are the standard errors of the difference between paired means. For global and local decisions on letters, SE = 3.56 and 7.76 ms respectively. For geometric shapes, SE = 2.51 and 3.87 ms respectively.

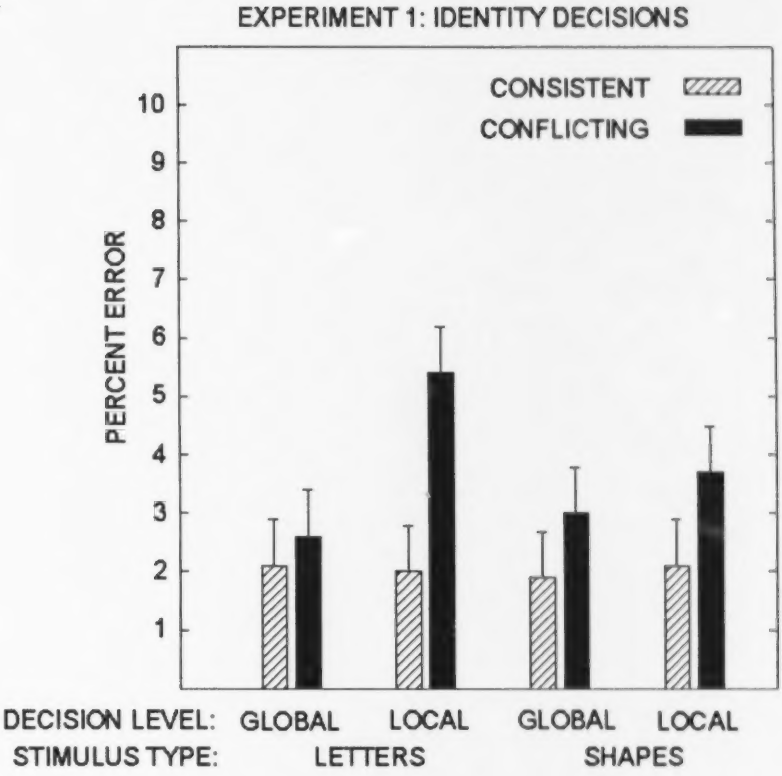

Figure 7. Mean percent error from Experiment 1. Confidence intervals (+/- .79) are computed using the MSe from the interaction, as recommended by Loftus and Masson (1993).

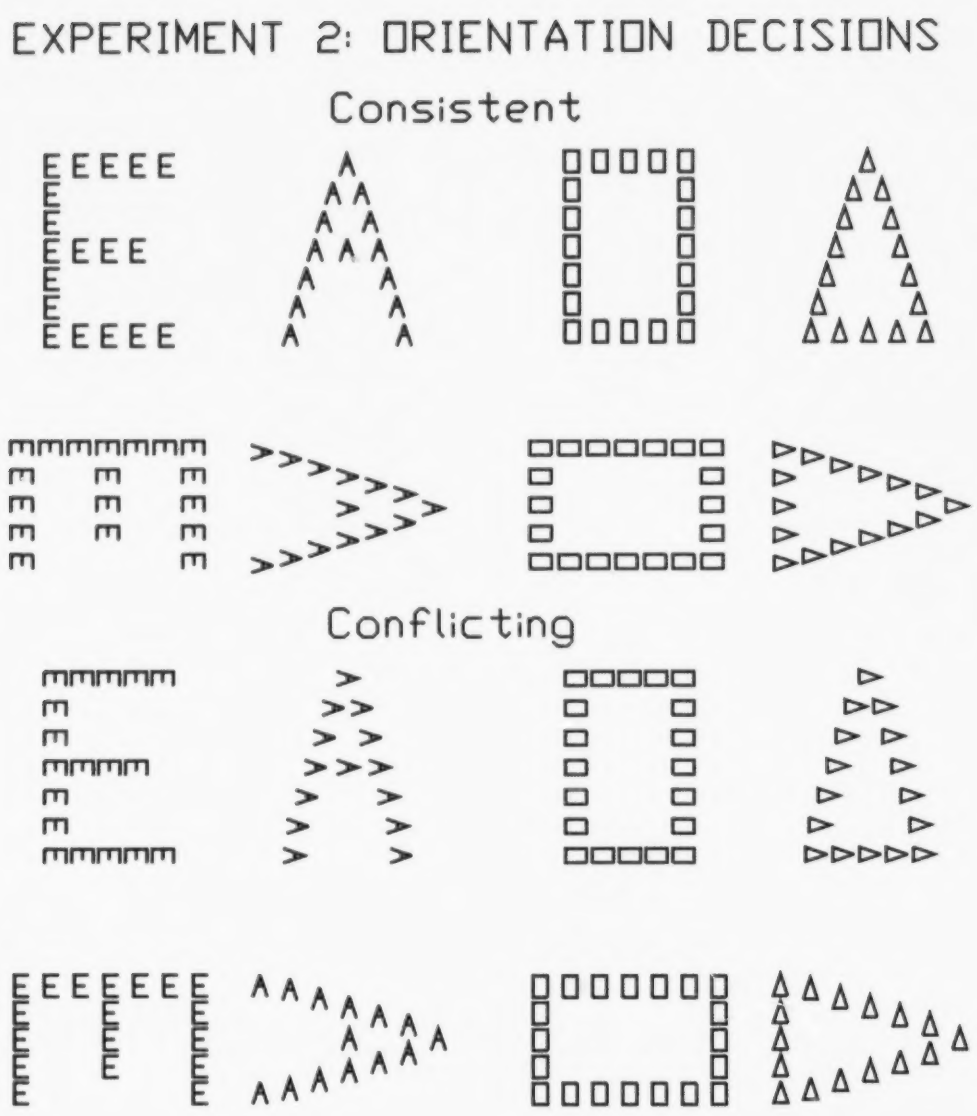

Figure 8. Stimuli used in Experiment 2.

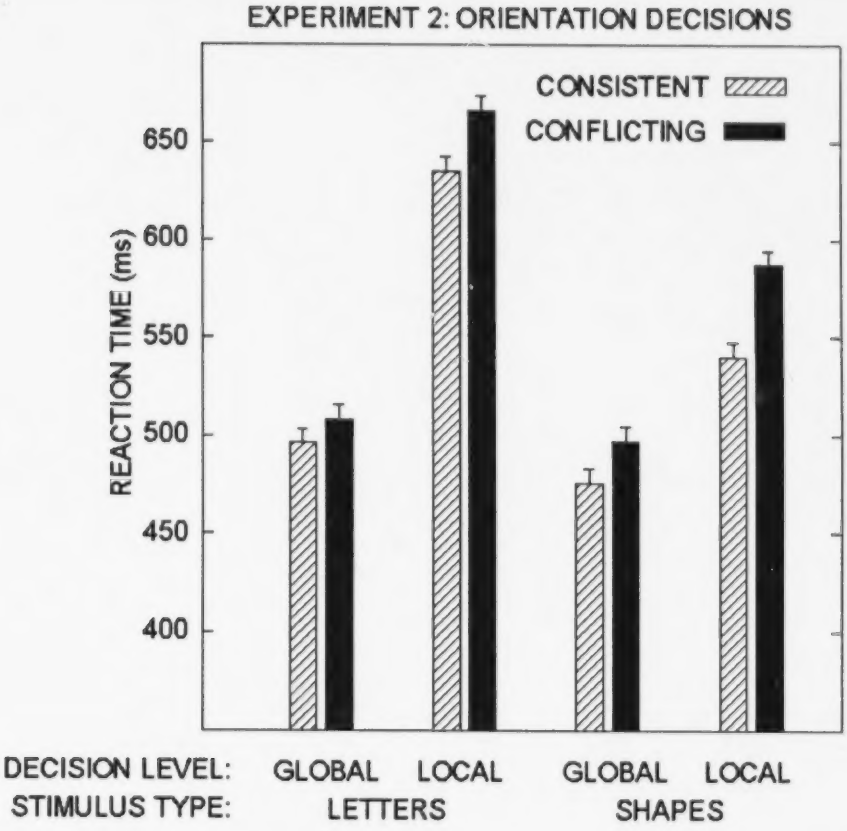

Figure 9. Mean RTs from Experiment 2. Confidence intervals (+/- 7.41 ms) are computed using the MSe from the interaction as recommended by Loftus and Masson (1993).

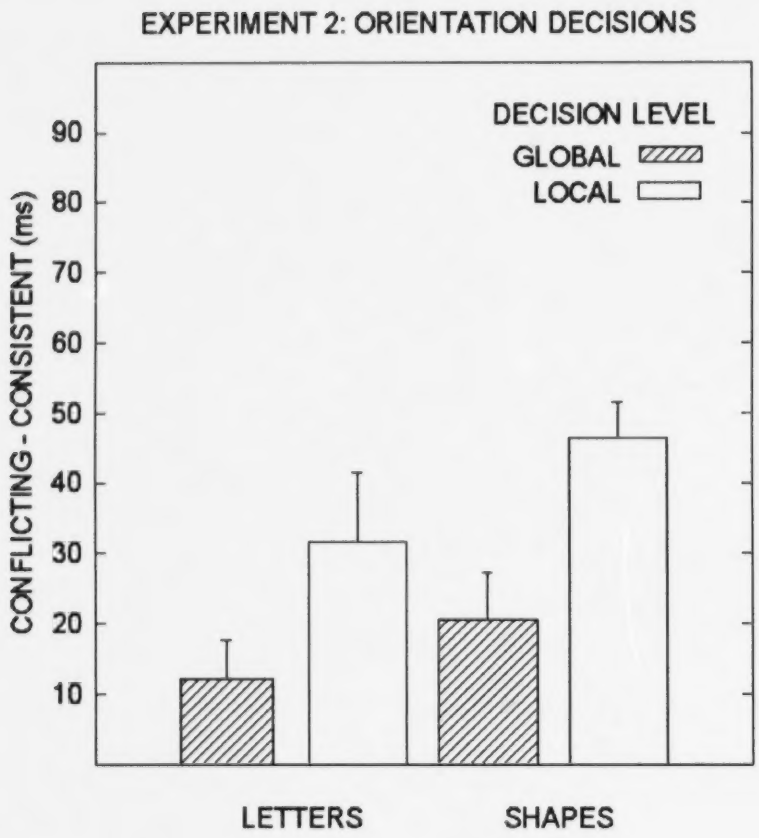

Figure 10. Global and local interference effects from Experiment 2. Global interference is shown as the difference between the local-conflicting and local-consistent conditions. Local interference is shown as the difference between the global-conflicting and global-consistent conditions. Standard error bars are the standard errors from the difference between paired means. For global and local decisions on letters, SE = 5.48 and 9.90 ms respectively. For geometric shapes, SE = 6.57 and 5.17 ms respectively.

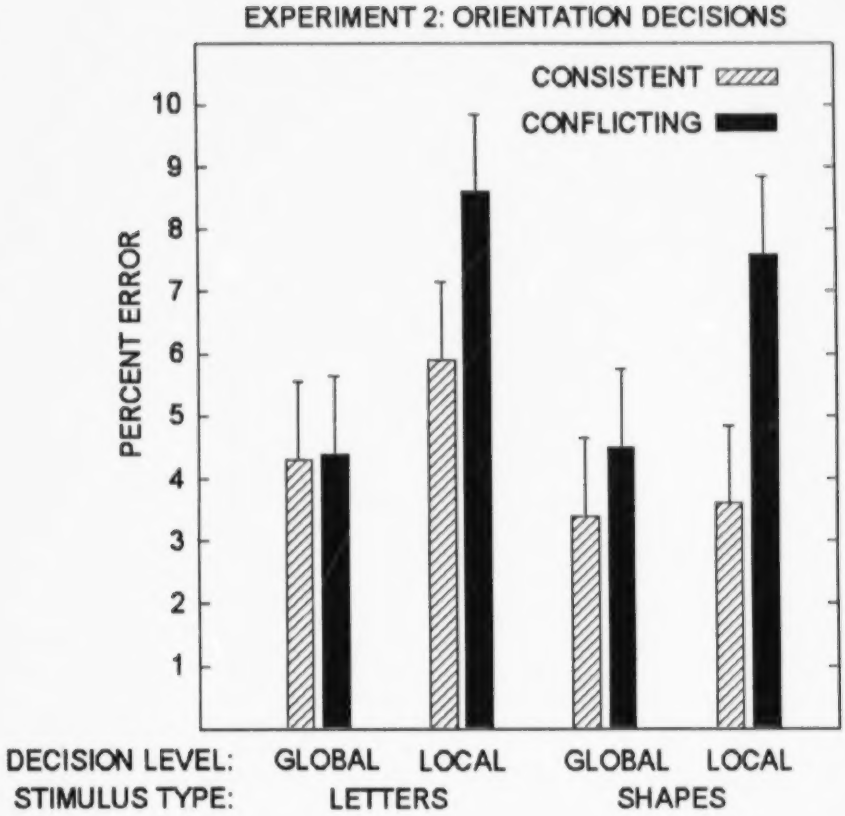

Figure 11. Mean percent error from Experiment 2. Confidence intervals (+/- 1.25) are computed using the MSe from the interaction as recommended by Loftus and Masson (1993).

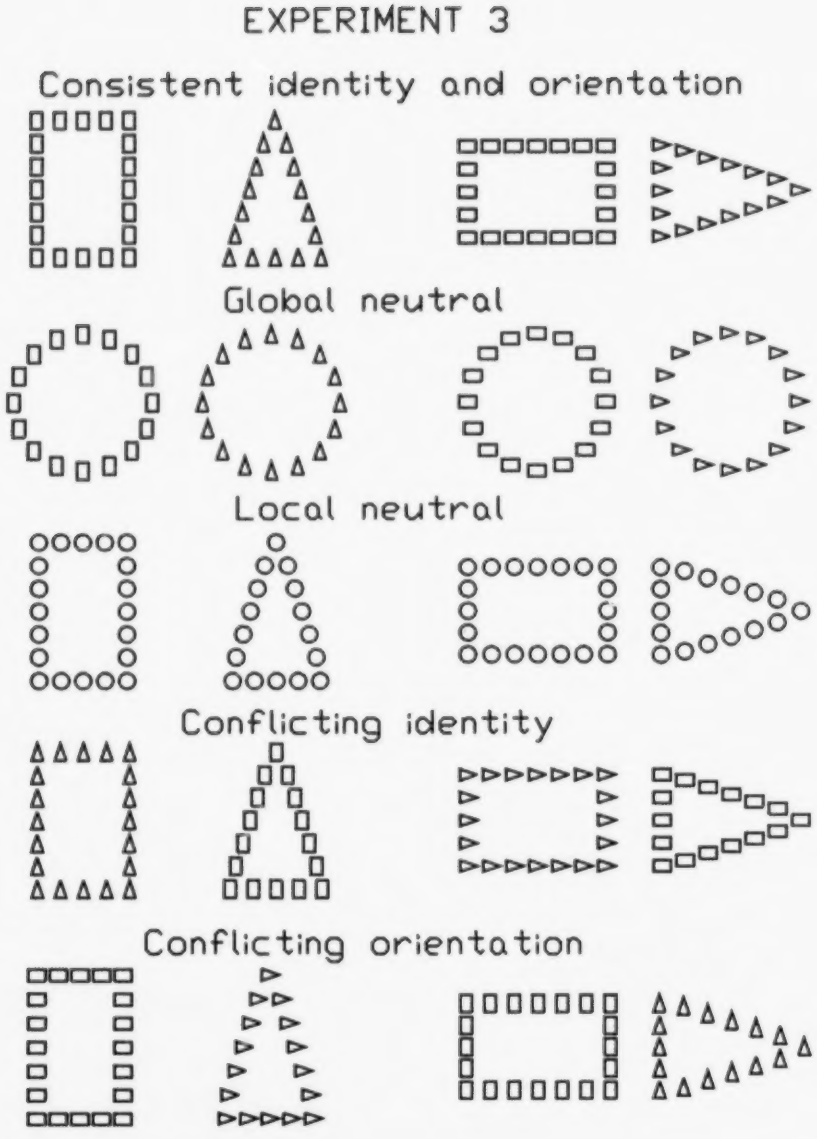

Figure 12. Stimuli used in Experiment 3. The left two columns are globally vertical. The right two columns are globally horizontal.

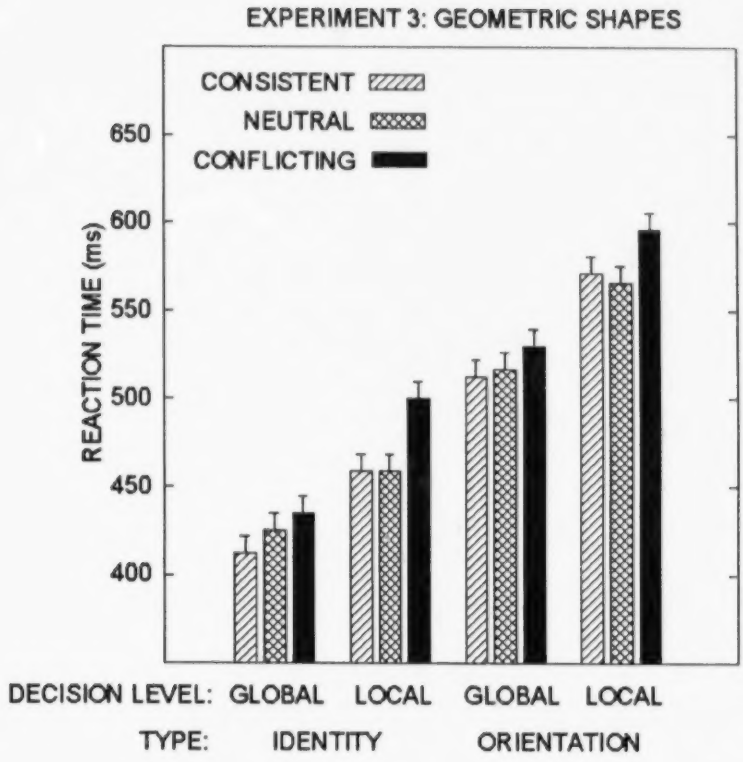

Figure 13. Mean RTs of correct trials from Experiment 3. Confidence intervals (+/- 9.68 ms) are computed using the MSe from the interaction as recommended by Loftus and Masson (1993).

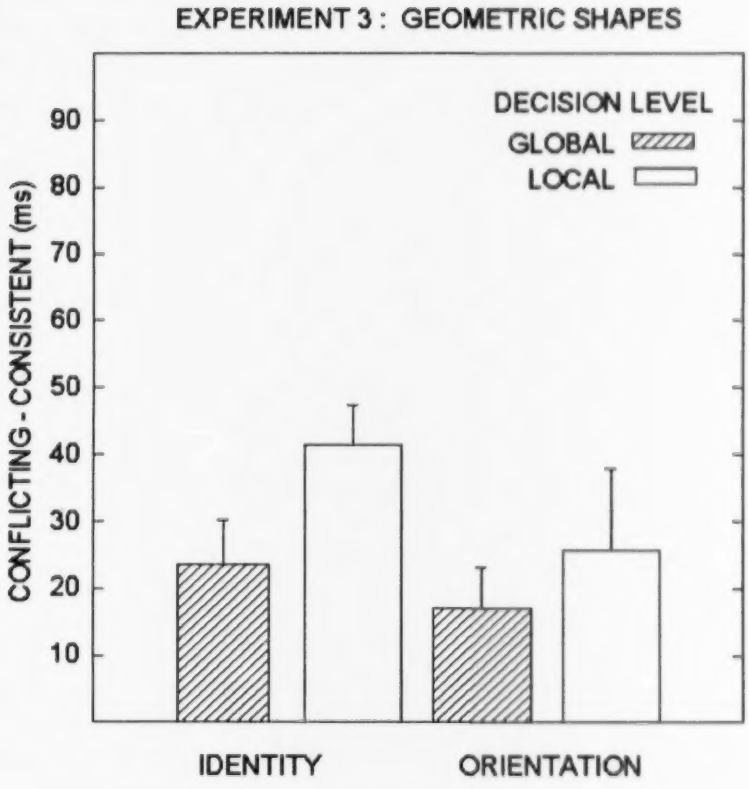

Figure 14. Global and local interference effects from Experiment 3. Global interference is shown as the difference between the local-conflicting and local-consistent conditions. Local interference is shown as the difference between the global-conflicting and global-consistent conditions. Standard error bars are the standard errors from the difference between paired means. For global and local identity decisions, SE = 6.84 and 5.94 ms respectively. For global and local orientation decisions, SE = 6.14, and 12.21 ms respectively.

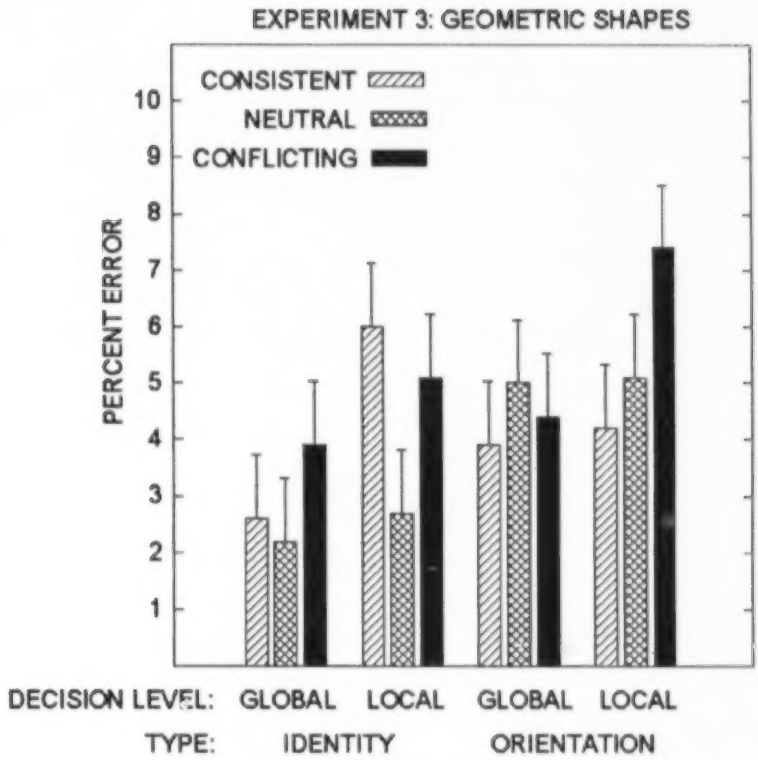

Figure 15. Mean percent error from Experiment 3. Confidence intervals (+/- 1.12) are computed using the MSe from the interaction as recommended by Loftus and Masson (1993).

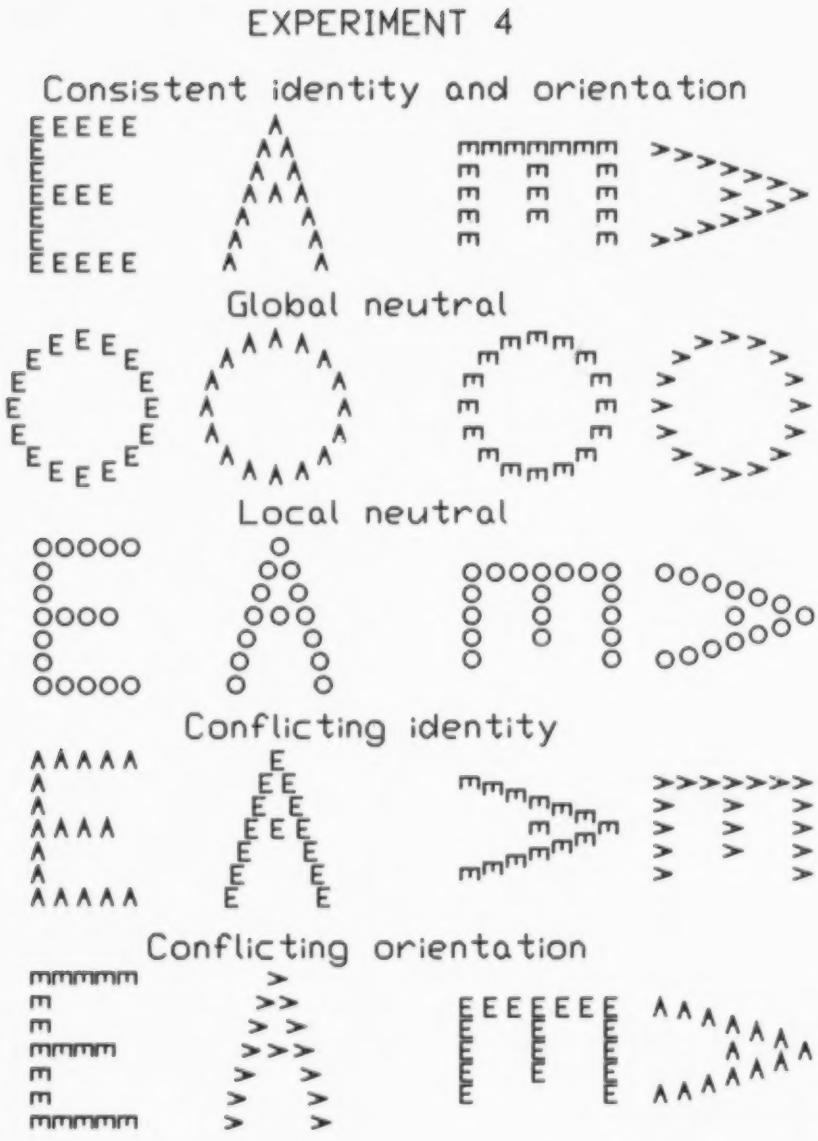

Figure 16. Stimuli used in Experiment 4. The left two columns are globally vertical. The right two columns are globally horizontal.

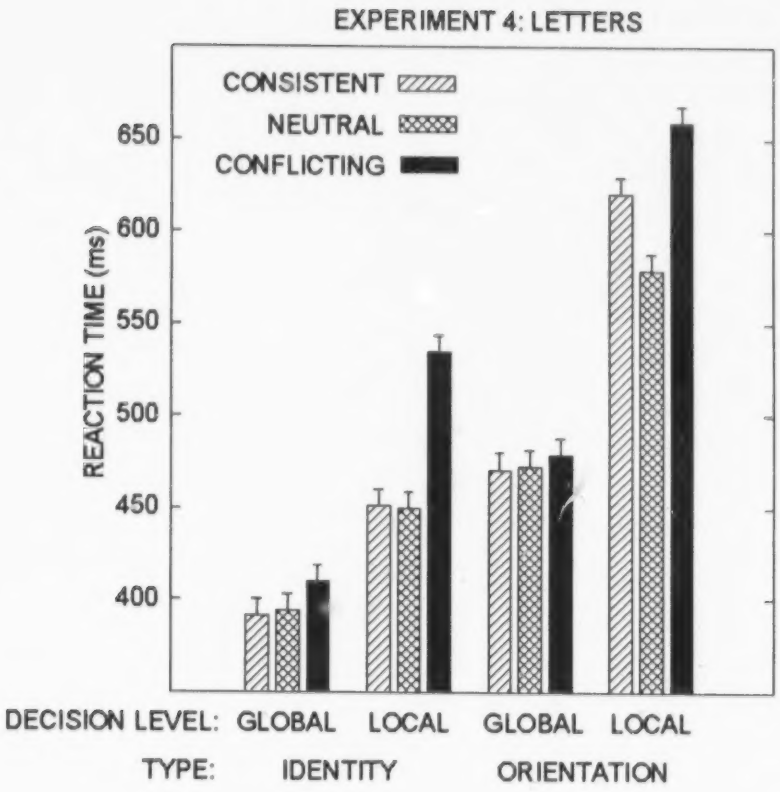

Figure 17. Mean RTs from Experiment 4. Confidence intervals (+/- 9.17 ms) are computed using the MSe from the interaction as recommended by Loftus and Masson (1993).

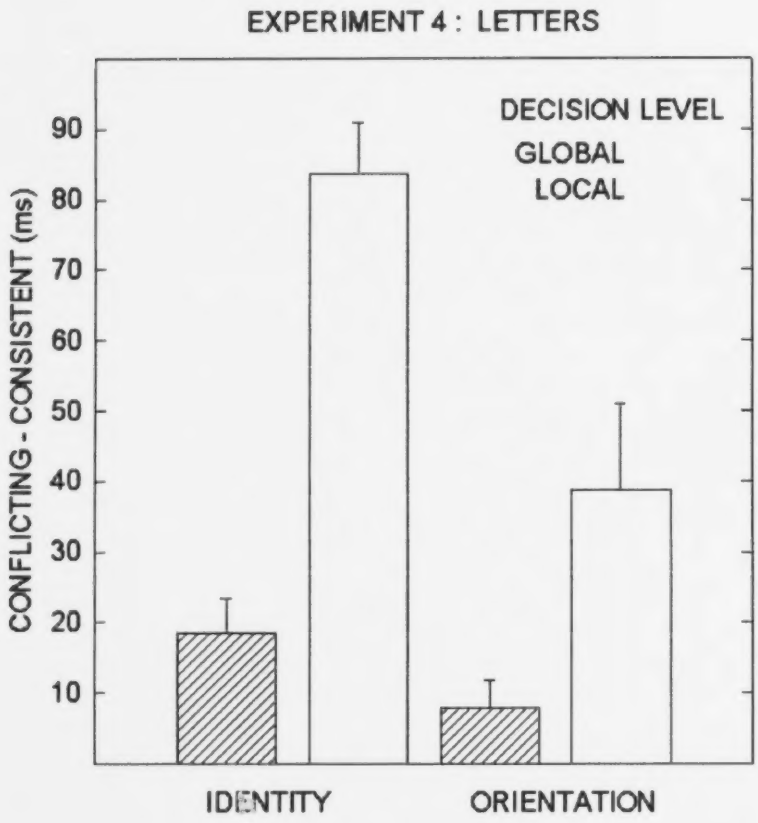

Figure 18. Global and local interference effects from Experiment 4. Global interference is the difference between the local-conflicting and local-consistent conditions. Local interference is the difference between the global-conflicting and global-consistent conditions. Standard error bars are the standard errors from the difference between paired means. For global and local identity decisions, SE = 4.93 and 7.25 ms respectively. For global and local orientation decisions, SE = 3.76 and 12.28 ms respectively.

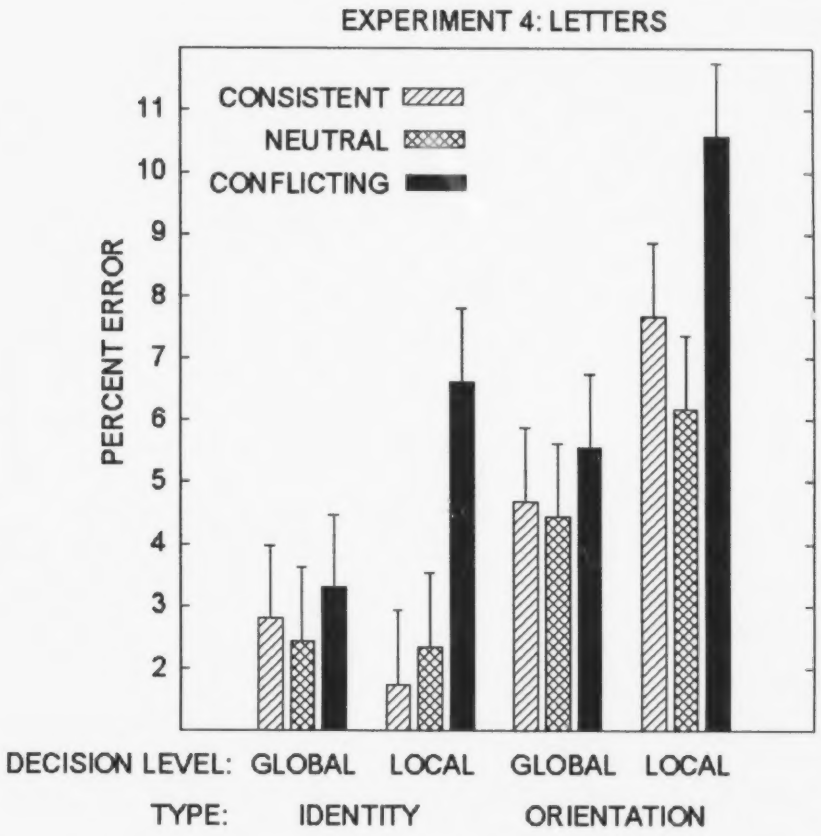

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Table 1
Mean Reaction Time (ms), Percent Error and Interference (Conflicting - Consistent) for Experiment 1. Standard Errors are in Parentheses

	Decision Level			
	Global		Local	
	RT	% error	RT	%error
Letters				
Consistent	357 (12.74)	2.1 (0.42)	418 (17.45)	20(0.60)
Conflicting	367 (13.66)	2.6 (0.50)	498 (20.65)	54(1.15)
Interference	10 (3.56)	0.5 (0.46)	80 (7.76)	33(1.21)
Geometric Shapes				
Consistent	354 (13.65)	1.9 (0.50)	388 (14.46)	21(0.71)
Conflicting	366 (13.87)	3.0 (0.45)	435 (14.39)	37(0.63)
Interference	12 (2.51)	1.1 (0.56)	48 (3.87)	16(0.81)

Table 2

Mean Reaction Time (ms), Percent Error and Interference (Conflicting - Consistent) for Experiment 2. Standard Errors are in Parentheses.

	Decision Level			
	Global		Local	
	RT	% error	RT	%error
Letters				
Consistent	496 (29.64)	4.3 (0.63)	635 (44.50)	59(1.15)
Conflicting	508 (30.53)	4.4 (0.77)	666 (40.71)	86(1.36)
Interference	12 (5.48)	0.1 (0.43)	32 (9.90)	27(098)
Geometric Shapes				
Consistent	476 (24.62)	3.4 (0.64)	540 (38.93)	36(1.13)
Conflicting	497 (27.84)	4.5 (0.69)	587 (37.99)	76(1.60)
Interference	21 (6.57)	1.1 (0.54)	46 (5.17)	40(098)

Table 3
Mean Reaction Time (ms), Percent Error, and Interference (Conflicting - Consistent) for Experiment 3. Standard Errors are in Parentheses

	Decision Level			
	Global		Local	
	RT	% error	RT	%error
Identity				
Consistent	412 (17.12)	2.6 (0.54)	459 (20.33)	6.0(1.07)
Neutral	425 (20.80)	2.2 (0.48)	459 (19.51)	2.7(0.78)
Conflicting	435 (20.46)	3.9 (0.83)	500 (18.44)	5.1(1.31)
Interference	23 (6.84)	1.3 (0.66)	41 (5.94)	-0.9(1.51)
Orientation				
Consistent	513 (28.66)	3.9 (0.75)	571 (25.34)	4.2(0.70)
Neutral	517 (26.28)	5.0 (0.90)	566 (21.30)	5.1(0.91)
Conflicting	530 (28.59)	4.4 (0.72)	596 (20.09)	7.4(1.34)
Interference	17 (6.14)	0.5 (0.64)	26 (12.21)	3.2(1.14)

Table 4

Mean Reaction Time (ms), Percent Error, and Interference (Conflicting - Consistent) for Experiment 4. Standard Errors are in Parentheses

	Decision Level			
	Global		Local	
	RT	% error	RT	%error
Identity				
Consistent	391 (12.00)	2.8 (0.73)	451 (15.22)	1.7 (0.38)
Neutral	394 (11.39)	2.4 (0.60)	450 (12.75)	2.4 (0.55)
Conflicting	410 (14.35)	3.3 (0.62)	535 (15.20)	6.6 (1.53)
Interference	19 (4.93)	0.5 (0.74)	84 (5.54)	4.9 (1.44)
Orientation				
Consistent	471 (14.97)	4.7 (0.84)	620 (27.50)	7.7 (0.92)
Neutral	473 (13.43)	4.4 (0.76)	578 (19.44)	6.2 (1.16)
Conflicting	479 (14.93)	5.6 (0.86)	659 (23.70)	10.6 (1.97)
Interference	8 (3.76)	0.9 (0.76)	39 (12.18)	2.9 (1.57)

Table 5
Sources of Variance for Reaction Time on Identity Decisions from Experiment 1. Stimulus Type (letter, geometric shape) x Decision Level (global, local) x Congruency (consistent, conflicting)

Source of Variance	df	Mean Square	F	p
Stimulus type	1	28190.64	6.76	.016
Within	23	4171.16		
Decision level	1	259491.78	77.19	.000
Within	23	3361.93		
Congruency	1	66845.35	207.07	.000
Within	23	322.82		
Stimulus Type x Decision Level	1	22739.64	8.63	.007
Within	23	2635.53		
Stimulus Type x Congruency	1	2832.85	12.52	.002
Within	23	226.20		
Decision Level x Congruency	1	33747.76	82.14	.000
Within	23	410.84		
Stimulus Type x Decision Level x Congruency	1	3337.50	19.71	.000
Within	23	169.29		

Table 6

Sources of Variance for Reaction Time on Orientation Decisions from Experiment 2. Stimulus Type (letter, geometric shape) x Decision Level (global, local) x Congruency (consistent, conflicting)

Source of Variance	df	Mean Square	F	p
Stimulus type	1	126177.52	34.54	.000
Within	23	3652.68		
Decision level	1	611556.75	29.24	.000
Within	23	20917.51		
Congruency	1	36852.08	79.91	.000
Within	23	461.17		
Stimulus Type x Decision Level	1	61436.41	8.09	.009
Within	23	7590.68		
Stimulus Type x Congruency	1	1636.25	2.94	.100
Within	23	556.50		
Decision Level x Congruency	1	6091.89	5.81	.024
Within	23	1048.04		
Stimulus Type x Decision Level x Congruency	1	115.63	.38	.546
Within	23	307.53		

Table 7
Sources of Variance for Reaction Time from Experiment 3, Decision Type (identity, orientation) x Decision Level (global, local) x Congruency (consistent, neutural, conflicting)

Source of Variance	df	Mean Square	F	p
Decision type	1	726112.92	64.00	.000
Within	23	11345.09		
Decision level	1	201559.59	30.52	.000
Within	23	6604.59		
Congruency	2	20717.19	45.92	.000
Within	46	451.15		
Decision Type x Decision Level	1	1446.77	.30	.589
Within	23	4830.97		
Decision Type x Congruency	2	757.17	1.19	.313
Within	46	634.72		
Decision Level x Congruency	2	3512.53	4.67	.014
Within	46	752.30		
Decision Type x Decision Level x Congruency	2	300.82	.55	.583
Within	46	550.71		

Table 8
Sources of Variance for Reaction Time from Experiment 4.
Decision Type (identity, orientation) x Decision Level (global, local) x
Congruency (consistent, neutral, conflicting)

Source of Variance	df	Mean Square	F	p
Decision type	1	841617.97	108.99	.000
Within	23	7722.20		
Decision level	1	911446.89	90.61	.000
Within	23	10058.90		
Congruency	2	58762.63	67.83	.000
Within	46	866.31		
Decision Type x Decision Level	1	75895.70	11.40	.003
Within	23	6655.59		
Decision Type x Congruency	2	4936.13	7.06	.002
Within	46	698.69		
Decision Level x Congruency	2	32105.21	31.95	.000
Within	46	1004.72		
Decision Type x Decision Level x Congruency	2	2733.10	5.53	.007
Within	46	494.08		

Table 9

Sources of Variance for Percent Error on Identity Decisions from Experiment 1, Stimulus Type (letter, geometric shape) x Decision Level (global, local) x Congruency (consistent, conflicting)

Source of Variance	df	Mean Square	F	p
Stimulus type	1	6.38	.65	.427
Within	23	9.75		
Decision level	1	36.51	9.16	.006
Within	23	3.98		
Congruency	1	127.86	11.63	.002
Within	23	10.99		
Stimulus Type x Decision Level	1	11.05	1.84	.188
Within	23	6.00		
Stimulus Type x Congruency	1	3.95	.51	.482
Within	23	7.74		
Decision Level x Congruency	1	33.79	3.47	.075
Within	23	9.75		
Stimulus Type x Decision Level x Congruency	1	15.63	4.50	.045
Within	23	3.47		

Table 10

Sources of Variance for Percent Error on Orientation Decisions from Experiment 2. Stimulus Type (letter, geometric shape) x Decision Level (global, local) x Congruency (consistent, conflicting)

Source of Variance	df	Mean Square	F	p
Stimulus type	1	49.98	6.07	.022
Within	23	8.24		
Decision level	1	253.97	6.91	.015
Within	23	36.73		
Congruency	1	188.25	25.56	.000
Within	23	7.36		
Stimulus Type x Decision Level	1	19.03	1.30	.267
Within	23	14.69		
Stimulus Type x Congruency	1	16.56	2.54	.125
Within	23	6.51		
Decision Level x Congruency	1	94.50	16.00	.001
Within	23	5.91		
Stimulus Type x Decision Level x Congruency	1	.25	.03	.868
Within	23	8.78		

Table 11
Sources of Variance for Percent Error from Experiment 3.
Decision Type (identity, orientation) x Decision Level (global, local) x Congruency (consistent, neutral, conflicting)

Source of Variance	df	Mean Square	F	p
Decision type	1	105.80	3.82	.063
Within	23	27.72		
Decision level	1	141.07	10.59	.003
Within	23	13.33		
Congruency	2	53.78	4.28	.020
Within	46	12.57		
Decision Type x Decision Level	1	5.36	.67	.421
Within	23	7.97		
Decision Type x Congruency	2	49.46	11.94	.000
Within	46	4.14		
Decision Level x Congruency	2	22.67	2.17	.126
Within	46	10.45		
Decision Type x Decision Level x Congruency	2	35.96	4.85	.012
Within	46	7.41		

Table 12

Sources of Variance for Percent Error from Experiment 4. Decision Type (identity, orientation) x Decision Level (global, local) x Congruency (consistent, neutral, conflicting)

Source of Variance	df	Mean Square	F	p
Decision type	1	790.18	35.76	.000
Within	23	22.10		
Decision level	1	286.48	15.46	.001
Within	23	18.53		
Congruency	2	198.91	12.90	.000
Within	46	15.42		
Decision Type x Decision Level	1	115.02	8.94	.007
Within	23	12.86		
Decision Type x Congruency	2	6.68	1.48	.238
Within	46	4.51		
Decision Level x Congruency	2	85.99	5.22	.009
Within	46	16.48		
Decision Type x Decision Level x Congruency	2	10.40	1.26	.294
Within	46	8.27		

Instructions to Subjects

During the trials you will need to use this headrest. I will explain more about it later on in the instructions; don't worry about it for now.

I want to point out to you that if you decide not to participate in this study for any reason, that you are free to leave, and that you will still receive credit for participation.

I also want to point out that I will READ the instructions to you to ensure that everyone participating receives the same instructions.

In this study, we are interested in how quickly and accurately people identify patterns that are shown in very brief displays. You will see patterns that briefly appear somewhere on the screen and then quickly disappear.

EXPERIMENT 1:

For this session, each pattern will be a large letter made of small letters. You are to identify the (LARGE/SMALL) letter as quickly and as accurately as you can.

EXPERIMENTS 2, 3 and 4:

For this session, each pattern will be a large (LETTER /SHAPE) made of small (LETTERS /SHAPES). The large (LETTER /SHAPE) will be either vertical or horizontal and the small (LETTERS /SHAPES) will be either vertical or horizontal. You are to identify the (SHAPE/ORIENTATION) of the (LARGE/SMALL) (LETTER/SHAPE) as quickly and as accurately as you can.

TOUCH-PLATE INSTRUCTIONS

Make your response by touching the corresponding small plate (INDICATE) using either your first or second finger. Rest your hand on the touch-plate like this (DEMONSTRATE) with your fingers resting on the wooden strips. Press the appropriate button using your index finger (DEMONSTRATE) or second finger (DEMONSTRATE). As soon as you respond, return your finger to the wooden strip (DEMONSTRATE).

If the (LARGE/SMALL) (LETTER/SHAPE) is (AN "E"/ A RECTANGLE /VERTICAL) press the plate below your forefinger, if the (LARGE/SMALL) (LETTER/SHAPE) is (AN "A"/ A TRIANGLE /HORIZONTAL) press the other plate using your second finger.

For this study, you begin each trial when you are ready by pressing this foot-switch (DEMONSTRATE). Rest your foot on the switch like this. When you are ready to start a trial, lift your foot and then press it down on the switch. After you press the switch, you

will hear a short beep, and a little cross will appear in the center of the screen. You should focus your attention on the center of the cross. Then, a target pattern will appear for a brief moment and disappear leaving a blank screen. You decide as quickly as you can whether the (LARGE/SMALL) (LETTER/SHAPE) was (AN "E" OR AN "A"/ A RECTANGLE OR A TRIANGLE / VERTICAL OR HORIZONTAL), and touch the corresponding touch-plate with the appropriate finger. You should respond as quickly, and as accurately as you can.

If your response is correct, the fixation cross will return to the screen. If your response is incorrect, you will hear two low beeps, and then the fixation cross will return. When you are ready for the next trial, press the foot-switch.

HEADREST INSTRUCTIONS

During the trials you will need to use this headrest. Your chin will be in this rest (INDICATE), your forehead against this bar (INDICATE) and these rings will be placed against your head so it is in a comfortable but stable position throughout the trials. (ADJUST HEADREST AND MICKEY MOUSE EARS, BEING CAREFUL THAT THE HEADREST REMAINS CENTERED).

I'll go over the sequence for you again. First, a cross will appear in the center of the screen (INDICATE). When you are ready to start a trial, press the foot-switch. There will be a short beep. Focus your eyes and attention on the center of the cross. A target pattern will briefly appear somewhere on the screen and disappear leaving a blank screen. You decide as quickly as you can whether the (LARGE/SMALL) (LETTER/SHAPE) was (AN "E" OR AN "A" / A RECTANGLE OR A TRIANGLE), and touch the corresponding touch-plate with the appropriate finger. You should respond as quickly, and as accurately as you can. Once you have responded, the cross will return. When you are ready, press the foot-switch for the next trial.

We will start with some practice trials so that you can get used to the task. You can start the trials when you are ready by pressing the foot-switch.

RUN PRACTICE BLOCK

Notice that when the trials were finished there were three fairly loud beeps. You will also hear this beeps at the end of each session so that you will know when the last trial is finished.

Do you have any questions about how to do the task?

There will be four sessions today. We will start the first session now. Remember to respond as quickly and as accurately as possible.

RUN EXPERIMENT BLOCK

SUBSEQUENT SESSIONS:

For this session, each pattern will be a large (LETTER/SHAPE) made of small (LETTERS/SHAPES). You are to (IDENTIFY / IDENTIFY THE ORIENTATION OF) the (LARGE/SMALL) (LETTER/SHAPE).

If the (LARGE/SMALL) (LETTER/SHAPE) is (AN "E"/ A RECTANGLE /VERTICAL) press the plate below your forefinger, if the (LARGE/SMALL) (LETTER/SHAPE) is (AN "A"/ A TRIANGLE /HORIZONTAL) press the other plate using your second finger.

As for all the sessions, respond as quickly and as accurately as you can.